GUIDELINES AND STANDARDS

Recommendations for the Identification and Mitigation of Cardiac Ultrasound Artifacts: A Guideline from the American Society of Echocardiography

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An ultrasound artifact is a feature in an ultrasound image that does not accurately represent the true anatomy or pathology. Cardiac ultrasound artifacts are common and inevitable findings as they originate from the physical properties of ultrasound. Additionally, artifacts may occur due to interference from external equipment and devices producing ultrasound waves. This document provides a uniform and structured approach to managing ultrasound artifacts, including the appearance of the artifact on the image, the mechanism behind the artifact generation, the clinical impact of the artifact on the diagnosis and management of the patient, examples of real cases, and how the artifact can be avoided or mitigated. In addition to true artifacts, we also discuss a series of artifact-like phenomena. Everyone involved in performing or interpreting cardiac ultrasound should be familiar with artifacts and their potential for misdiagnosis, which in some instances may lead to serious clinical consequences. Despite continued improvements in ultrasound imaging technologies, artifacts remain common in all echocardiographic modes, including two-dimensional, spectral, and color Doppler, as well as three-dimensional echocardiography. (J Am Soc Echocardiogr 2026;39:435-75.)

Keywords: Aliasing, Artifacts, Doppler, Echocardiography, Ultrasound

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TABLE OF CONTENTS

Abbreviations

2D = Two-dimensional

3D = Three-dimensional

AR = Aortic regurgitation

ASE = American Society of Echocardiography

CMR = Cardiac magnetic resonance

CWD = Continuous-wave Doppler

HPRF = High pulse repetition frequency

LA = Left atrium

LAA = Left atrial appendage

LV = Left ventricle

LVAD = Left ventricular assist device

LVOT = Left ventricular outflow tract

MI = Mechanical index

MR = Mitral regurgitation

NFC = Near field clutter

PISA = Proximal isovelocity surface area

PRF = Pulse repetition frequency

PWD = Pulsed-wave Doppler

TEE = Transesophageal echocardiography

TR = Tricuspid regurgitation

TTE = Transthoracic echocardiography

UEA = Ultrasound-enhancing agent

VAD = Ventricular assist device

1. DEFINITION AND CLASSIFICATION OF CARDIAC ULTRASOUND ARTIFACTS

An ultrasound artifact is a feature in an ultrasound image that does not accurately represent the true anatomy or pathology. Cardiac ultrasound artifacts may present image elements in different ways, such as displacement, misplacement, distortion, masking, enhancing, and duplication. Artifacts are inevitable and commonly encountered in daily clinical practice. They inherently originate from the physical properties of ultrasound waves when interacting with tissues or during the image reconstruction process. Additionally, artifacts may occur due to interference from external equipment and devices producing ultrasound waves. Artifacts occur in all modes of echocardiography, including two-dimensional (2D) and three-dimensional (3D) imaging, spectral Doppler, and color Doppler imaging, as well as with the use of ultrasound-enhancing agents (UEAs).[1-3] Many therapeutic plans and surgical interventions are based on echocardiographic findings, highlighting the critical role of echocardiography in accurately diagnosing cardiac diseases. It is essential for echocardiographers to be familiar with ultrasound artifacts to avoid misdiagnoses.

In addition to true artifacts, we also discuss a series of artifact-like phenomena that may not technically be ultrasound artifacts. They may be related to improper machine settings (such as overgain) or may represent true findings that are sometimes improperly referred to as artifacts (such as mechanical valve clicks). It is essential for the echocardiographer to recognize and properly interpret these mimickers and adjust them accordingly (Table 1).

Following the general description of artifacts, we also highlight certain artifacts with potentially serious clinical consequences if they are mistaken for or interfere with the visualization of serious

Table 1 Classification of ultrasound artifacts or artifact-like phenomena

	Artifacts	Artifact-like phenomena
2D imaging in axial direction	Simple reverberation artifact Complex reverberation artifact Mirror image artifact Acoustic shadowing Acoustic enhancement Speed displacement (propagation velocity) artifact	
2D imaging in lateral direction	Refraction artifact Beam width and slice thickness artifacts Side lobe artifact	
Spectral Doppler imaging	Doppler beam width artifact Tiger stripes artifact Mirror image/duplication artifact Double envelope Doppler flow pattern	Overgain and undergain in spectral Doppler Spectral wall filter Velocity scale error/aliasing Noncoaxial intercept angle in spectral Doppler Spectral broadening/transit time effect Spectral Doppler click
Color Doppler imaging	Acoustic shadowing of color Doppler Color Doppler mirror artifact Color Doppler reverberation and refraction Color Doppler beam width artifact Color Doppler side lobe artifact/color splay	Color Doppler aliasing Color Doppler blooming and twinkling
3D echocardiography	Stitching (reconstruction) artifact 3D dropout artifact 3D blurring and blooming artifact Shadowing and reverberation artifacts	
Imaging with UEAs	Attenuation artifact UEA shadowing artifact UEA swirling UEA Doppler blooming	
Miscellaneous	Artifacts related to ultrasound equipment and devices	

pathologic findings, as well as beneficial artifacts that contribute to the correct clinical diagnosis. Each artifact is presented in a systematic manner, describing its appearance, recognition in the echocardiographic image, examples of the artifact, mechanism of artifact generation, clinical relevance of the artifact, and methods that can be used to avoid or mitigate artifacts.

1.1. Principles of Artifact Generation

Ultrasound image formation is based on transmitting ultrasound waves to the tissue and receiving signals via a transducer containing piezoelectric crystals that can convert electrical current to ultrasound waves and vice versa. As the ultrasound waves traverse tissue, some degree of attenuation occurs, which mainly depends on transducer frequency. Most of the waves will be reflected, transmitted, or refracted (Figure 1A). The ultrasound system will then generate images from the reflected waves, taking into account multiple factors, including ultrasound travel time and energy loss.[4-7] Ultrasound artifacts can be categorized into 2 groups: (1) artifacts due to violations of ultrasound system assumptions and (2) artifacts due to other mechanisms.

1.2. Ultrasound System Assumptions

These are the basic assumptions for image creation intrinsic to all ultrasound systems:[8,9]

- Ultrasound waves travel along a straight path.
- Each transmitted ultrasound beam has a single round trip.
- There is a uniform speed of the ultrasound waves in tissue (1,540 m/s).
- The ultrasound imaging preferentially depicts objects originating from the main lobe of the ultrasound beam.
- There is uniform attenuation of ultrasound waves in tissue (0.5 dB/cm/MHz).

Violation of 1 or more assumptions may result in the formation of artifacts in a predictable manner. Ultrasound assumption violation artifacts can be categorized based on their location in relation to the real structure. Axial artifacts are located distal to the real structure and are subcategorized into reverberation, mirror image, acoustic shadowing, enhancement artifacts, and speed displacement artifacts. Lateral direction artifacts are located to the side of the real imaged structure and are subcategorized into side lobe, beam width, and refraction artifacts (Figure 1B). In addition to ultrasound system assumption violations within native tissue, some artifacts arise due to interaction with a variety of foreign objects, including wires, catheters, devices, and external equipment.

2. TWO-DIMENSIONAL IMAGING ARTIFACTS IN AXIAL DIRECTION

2.1. Reverberation Artifacts

Reverberation artifacts occur primarily because the ultrasound system's assumption of a single round trip is violated. This assumption implies that the ultrasound travels from the transducer to the target

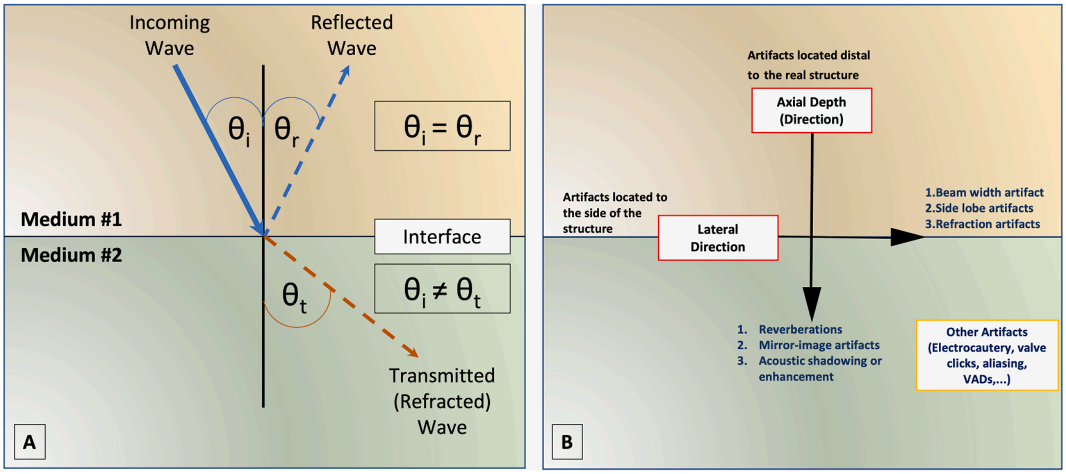

Figure 1 Ultrasound image generation and artifacts categorization. **(A)** Basics of 2D image generation. Ultrasound waves created by the transducer strike the interface between medium 1 and 2 *(blue arrow)* at an angle called the angle of incidence (θi). Ultrasound waves are partly reflected (*blue dotted arrow*) and usually mostly transmitted to medium 2 *(red dotted arrow)*. If there is an oblique incidence and a significant difference in propagation speeds between the 2 media, the transmitted wave is bent (refracted). **(B)** Schematic illustration of assumption violation artifacts based on location relative to the true image.

tissue and back only once during each ultrasound pulse (Video 1). Reverberation artifacts do not respect anatomic boundaries and have movement along the same axis as the target tissue.

2.2. Simple Reverberation Artifact

Appearance in image. The ultrasound system maps the original structure as a true image with the correct distance and the artifactual image (ghost image) distal to the original structure at twice the distance (Figure 2).

Left atrial appendage (LAA) artifact. Reverberation artifacts in the LAA arise from the left atrial ridge between the LAA and the left upper pulmonary vein and could be misinterpreted as a thrombus (Figure 3, Video 2).[1,10]

Ascending aorta artifact. Reverberation artifacts are a common finding in the ascending aorta (detected in 44%-55% of studies) and may lead to misdiagnosis of type A aortic dissection (Figure 4, Video 3).[11] With transesophageal echocardiography (TEE), the aortic root artifacts are typically due to reverberation from the anterior wall of the left atrium (LA). In contrast, in the middle third of the ascending aorta, reverberation artifacts generally arise from the main pulmonary artery wall or the wall of the right pulmonary artery.[11,12]

Mechanism. The ultrasound system measures the time interval between the sent and received signal (travel time or time of flight) to determine the distance between the transducer and the actual structure. Simple reverberation artifacts occur when the ultrasound pulse makes 2 round trips to the target tissue

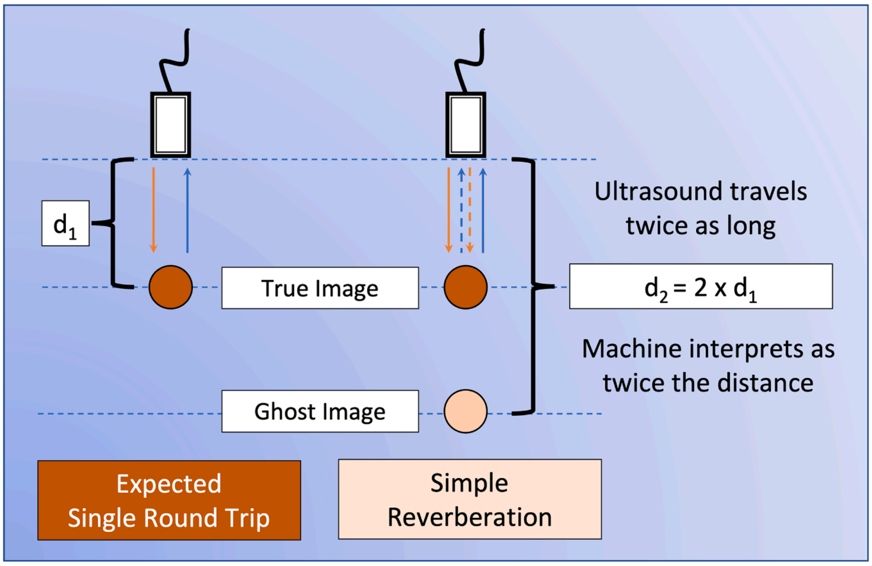

Figure 2 Basics of simple reverberation artifact. Ultrasound systems assume that wave travels back to the transducer after a single round trip and interpret the true image *(red circle)* to be at the distance ($d1$) calculated on the basis of this rule. In simple reverberation artifact, this rule is violated; the ultrasound wave travels one more time between the strong reflector and the probe itself (as shown in this diagram). The transducer interprets another image *(pink circle)* as being twice as deep ($d_2 = 2 \times d_1$).

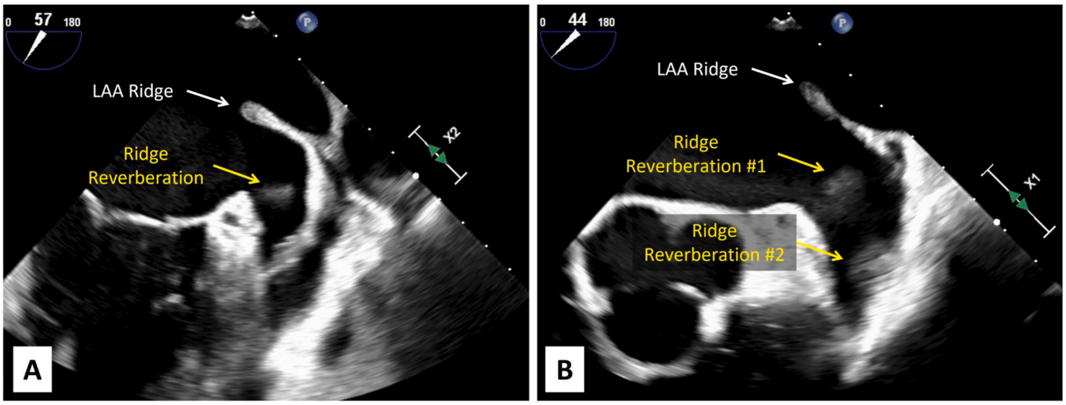

Figure 3 Two-dimensional reverberation artifacts in the LAA. **(A)** Two-dimensional TEE midesophageal views of the LAA. Reverberation artifacts in the LAA arising from the LAA ridge *(yellow arrow)*. **(B)** Second reverberation artifact deeper into the LAA *(yellow arrow #2)*. Note that the true structure and the artifacts are coaxial and equidistant. These ghost images could be falsely interpreted as thrombi.

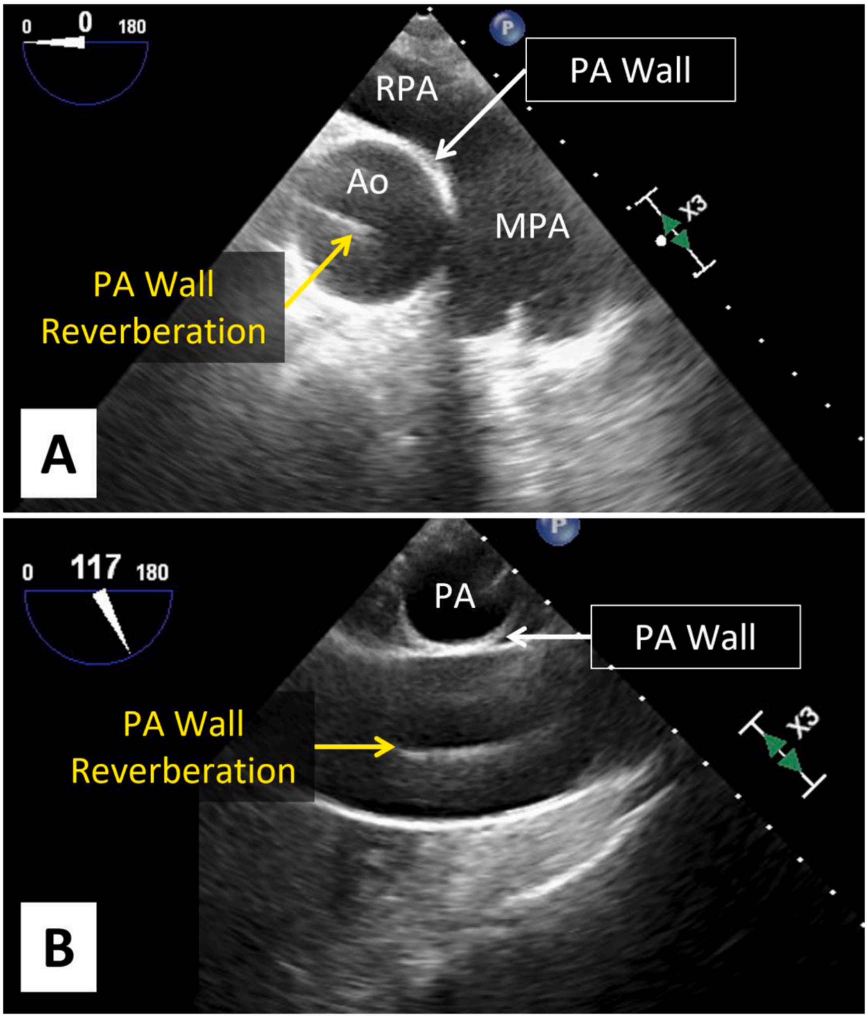

Figure 4 Two-dimensional simple reverberation artifact in the ascending aorta (Ao). Two-dimensional TEE, high-esophageal short-axis **(A)** and long-axis **(B)** views of the ascending Ao. The reverberation artifacts *(yellow arrows)* arise from the pulmonary artery (PA) wall *(white arrows)* and might be misdiagnosed as type A aortic dissection. *MPA*, main pulmonary artery; *RPA*, right pulmonary artery.

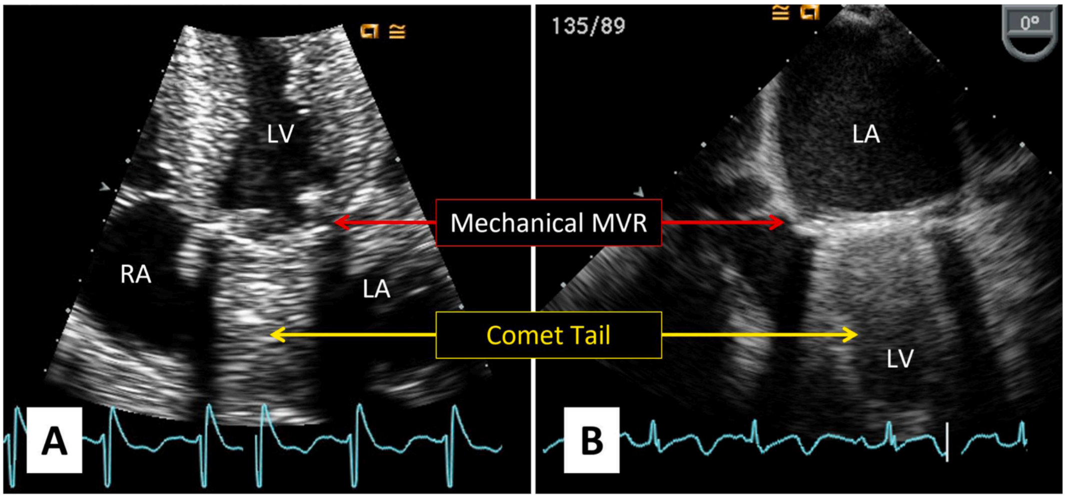

Figure 5 Two-dimensional complex reverberation artifact: comet tail artifact of a mechanical valve. Two-dimensional TTE apical four-chamber view **(A)** and 2D TEE midesophageal four-chamber view **(B)** reveal comet tail artifact *(yellow arrows)* originating from the bileaflet mechanical mitral valve *(red arrows)*. The artifact masks structures in the LA by TTE **(A)** and in the LV by TEE **(B)**. *MVR*, Mitral valve replacement; *RA*, right atrium.

and the ultrasound system interprets it as a longer travel time and generates an artifactual image twice as deep as the actual image. This occurs when the ultrasound pulse encounters a second strong reflector on its return to the transducer. The first reflector is the target tissue. The second reflector may be the transducer itself or some other strong reflector near the transducer, such as calcifications or implanted devices.

2.3. Complex Reverberation Artifact

Appearance in image. When there is close proximity of 2 or more strong reflectors, the reverberation artifact appears as a stepladder or trail that fades and tapers distally and is sometimes called a "comet tail" artifact. These echo signals are not individually discernible and resemble a comet's tail in the shape of a tapering triangle distal to a strongly reflecting surface.

Cardiac implants. Implanted cardiovascular devices such as mechanical valve prostheses, pacing wires, and catheters are common causes of complex reverberation artifacts (Figure 5, Video 4).

Lung ultrasound A lines. On lung ultrasound, repeated reverberation artifacts originating from the pleura and extending into the lung fields appear as repetitive, evenly spaced horizontal lines. They are visible in the normal lung but may also be seen in some pathological conditions such as pneumothorax and chronic obstructive pulmonary disease (Figure 6A, Video 5).

Lung ultrasound B lines. Lung B lines appear as linear hyperechoic and dynamic artifacts that slide with the lung in the vertical axis of the ultrasound beam and continue to the bottom of the image without fading. Lung ultrasound B lines represent a creative diagnostic use of complex ring-down artifacts rather than simple reverberation artifacts (Figure 6B, Video 5).[13] Ring-down artifacts are caused by resonant vibrations of trapped fluid within air bubbles, appearing as parallel bands, while reverberation artifacts arise from repeated reflections between highly reflective, parallel structures, creating a ladder-like or comet tail appearance. B lines were originally believed to result from complex comet tail reverberations but are now understood to arise from a different mechanism.

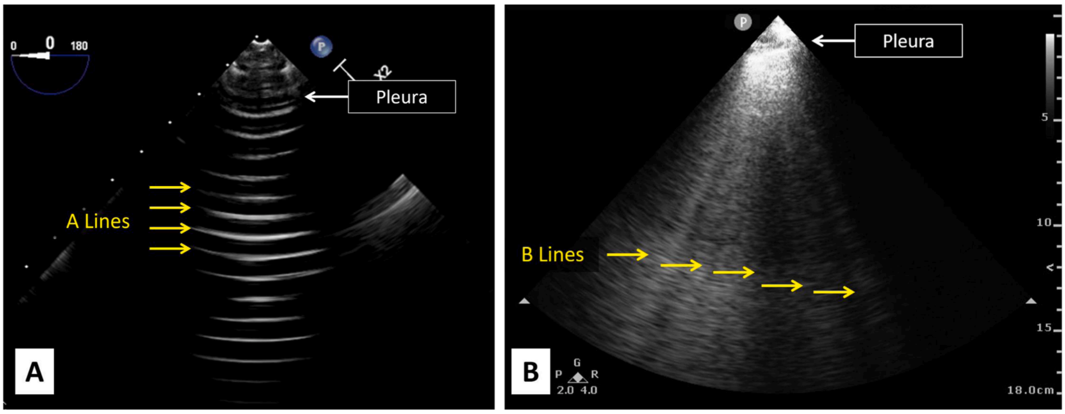

Figure 6 Lung ultrasound artifacts. **(A)** Two-dimensional TEE midesophageal view of the left lung; the A lines *(yellow arrows)* are equally spaced reverberation artifacts that arise from the pleural line *(white arrow)*. **(B)** Two-dimensional ultrasound image of the lung. The vertical, closely stacked lines *(yellow arrows)* are B-line artifacts. The B lines originate from the ring-down artifacts, which are caused by resonant vibrations of the trapped fluid within air bubbles and continue to the end without fading.

Mechanism. Complex reverberation artifacts often arise from simultaneous violations of 2 basic ultrasound system assumptions: single round-trip and uniform ultrasound speed transmission. The basic mechanism for complex reverberation is the same as in simple reverberation, except that the ultrasound wave gets "trapped" between 2 parallel strong reflectors bouncing back and forth. This process can repeat itself in an endless loop, leading in multiple parallel lines with progressively weaker intensity that extend to the bottom of the screen.[1] Additionally, the reflecting object (such as a mechanical prosthetic leaflet) may contribute to the artifact due to a difference in ultrasound speed propagation. This artifact may limit the evaluation of the structures in the far field. Decreasing the ultrasound gain and changing the imaging angle may reduce or eliminate the reverberation artifact from the region of interest.[14]

Key Points

- Reverberation artifacts can potentially be mistaken for real anatomic structures (such as thrombi in the LAA or aortic dissection flaps), leading to misdiagnosis, unnecessary procedures, unnecessary anticoagulation therapy, or even surgery.
- Reverberation artifacts commonly have movement along the same axis as the target tissue, do not respect anatomic boundaries, and lack clinical correlation.
- Comet tail artifact originating from mechanical mitral valve prostheses is a form of complex reverberation artifact that masks the evaluation of cardiac structures distal to the prosthesis, such as the LA on transthoracic echocardiography (TTE) and left ventricle (LV) on TEE imaging of mitral prostheses. On TTE imaging, this may prevent proper evaluation of prosthetic mitral regurgitation (MR) by color Doppler.

Recommendations

- Adjust the transducer angle (angle of insonation).
- Change the TTE/TEE probe position.
- Decrease gain settings (lowering gain can help reduce excessive echoes, such as reverberations).
- Recognize the reverberation artifact (it may not always be eliminated).
- No mitigation strategy is necessary for lung ultrasound, as the A lines and B lines are diagnostic on their own and are frequently used during point-of-care ultrasound evaluations.
- Utilize 3D echocardiography, UEA, and other cardiac imaging modalities, such as cardiac computed tomography and cardiac magnetic resonance (CMR) imaging, when an artifactual image cannot be distinguished from the actual structure.

2.4. Mirror Image Artifact

Appearance in image. The mirror image artifact is a false mirrored image of the actual object that is inverted in the axial direction and seen on the opposite side of a strong specular reflector, such as the pericardium, diaphragm, or aortic/pleural interface.[15]

Mitral valve. The mirror image appearance of the mitral valve and its surrounding structures in the parasternal long-axis view is a common artifact that happens due to the highly reflective pericardial surface (Figure 7, Video 6).[2]

Duplicated blood vessels. Double-barreled aorta from the suprasternal window and double-barreled inferior vena cava from the subcostal window are among the commonly

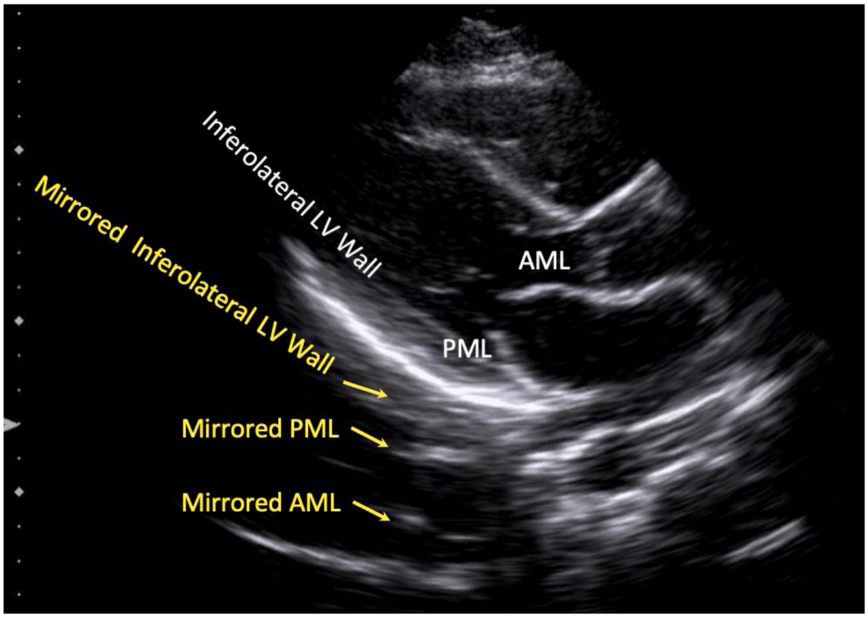

Figure 7 Two-dimensional mirror image artifact of the mitral valve. The 2D TTE parasternal long-axis view depicts a mirror image artifact of the mitral valve. The part of the ultrasound wave that is reflected to the object by the pericardium and back to the pericardium travels a longer distance back to reach the transducer. The longer distance is interpreted as another image mirrored distal to the true image on the other side of the reflector (pericardium in this example). Note that both the true and mirrored images are seen in the same frame distal to the true image of the left heart. The mirrored anterior and posterior mitral leaflets and mirrored inferolateral LV wall are noted with *yellow arrows*. This figure corresponds to Video 6. *AML*, Anterior mitral leaflet; *PML*, posterior mitral leaflet.

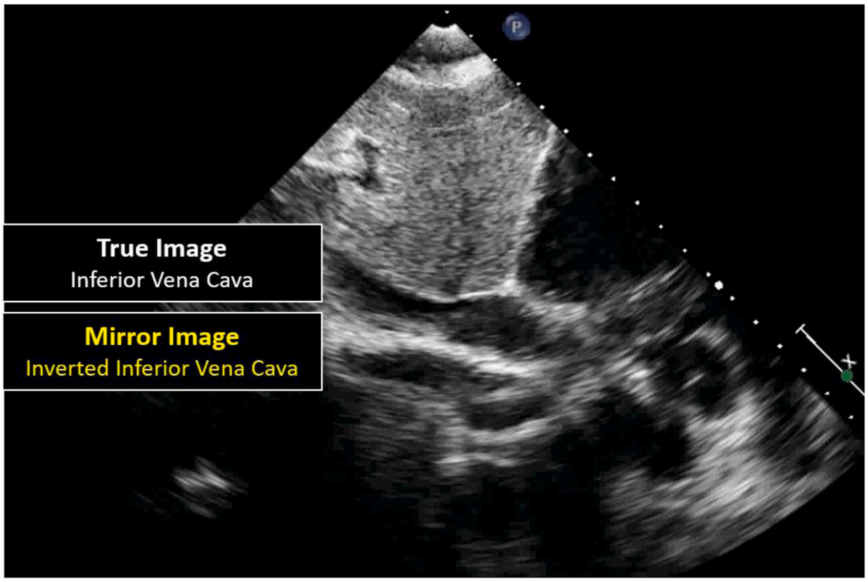

Figure 8 Two-dimensional mirror image artifact of the inferior vena cava. The 2D TTE subcostal view shows a duplicated inferior vena cava due to a mirror image artifact.

encountered examples of mirror image artifacts that complicate the evaluation of the major vessels on TTE (Figure 8, Video 7).[16]

Mechanism. The mirror image artifact violates 2 ultrasound assumptions: (1) that the ultrasound wave travels in a straight path and (2) that echoes return after a single reflection. Initially, the sound waves from the transducer encounter the object of interest (e.g., the mitral valve) and a highly reflective surface (e.g., pericardium). The reflected waves from the actual structure (e.g., the mitral valve) return to the transducer and create the true image. The sound waves reflect off the strong specular reflectors and are angled toward the cardiac structure, such as the mitral valve, which reflects the waves back to the pericardium and back to the transducer. These reflected waves have a longer transit time than waves reflected off the true structure, resulting in the machine displaying the false image distal and on the opposite side of the reflector (Videos 6 and 8).

This is analogous to an actual mirror (hence the accurate term for this artifact) with angulation of the reflector and equal angles of incidence and reflection determining the lateral shift of the false image, as well as the proximity of the reflected structures to the true structure (the posterior mitral leaflet being closest to the pericardium on both sides of the pericardial reflector; Figure 7).

Mirror image artifacts, therefore, involve complex multiple-angle reflections, in contrast to reverberation artifacts, in which only 1 ultrasound assumption is violated (single round trip). Occasionally, mirror images appear alone on the screen without visualization of the original structure.

Key Points

- The mirror image of vessels can be misdiagnosed as a dissection flap in a vessel.
- On TTE, the mirror image artifact in the parasternal long axis can be misinterpreted as a left pleural effusion.
- Mirror image artifacts should be suspected when a duplicated structure appears inverted and moves in the opposite direction, particularly in the presence of a highly reflective interface such as the pericardium.

Recommendations

- Recognize the potential for mirror image artifact by identifying the presence of a strong specular reflector in the ultrasound beam path.
- Optimize the gain settings to minimize the false image (multiply reflected waves will be more attenuated and therefore weaker).
- Change the imaging plane or the angle of the ultrasound beam to either remove the reflector from the scanning path or shift the angle of the transducer to change the angle at which sound waves will reflect off the strong reflecting structure, thereby abolishing the mirror image artifact.

2.5. Acoustic Shadowing

Appearance in image. Acoustic shadowing is characterized by the complete or partial lack of image details distal to the highly reflective structure. These anechoic or hypoechoic signals are typically depicted as a dark or "shadowed" area distal to the strong reflector. Strong reflectors that may lead to acoustic shadowing include dense valvular calcifications, excessive amounts of agitated saline or UEA, prosthetic valves, pacemakers, and implantable cardioverter-defibrillator leads. Sewing rings of both bioprosthetic and mechanical valves generate shadowing artifacts, while mechanical prosthetic leaflets generate additional complex reverberation artifacts (Figure 9, Video 9).

Shadowing artifacts may prevent full evaluation of tissue structures distal to the offending reflector. This is particularly important when evaluating prosthetic valves in apical views on TTE, as shadowing artifacts (together with reverberation artifacts) in the LA may prevent the detection of abnormalities such as MR or left atrial thrombi.[17,18]

Mechanism. This artifact occurs when the transmitted ultrasound beam is partly or completely reflected back to the transducer, preventing its propagation to distal structures. It occurs with highly reflective structures or at an interface having a high acoustic impedance mismatch (such as a soft tissue/air interface).

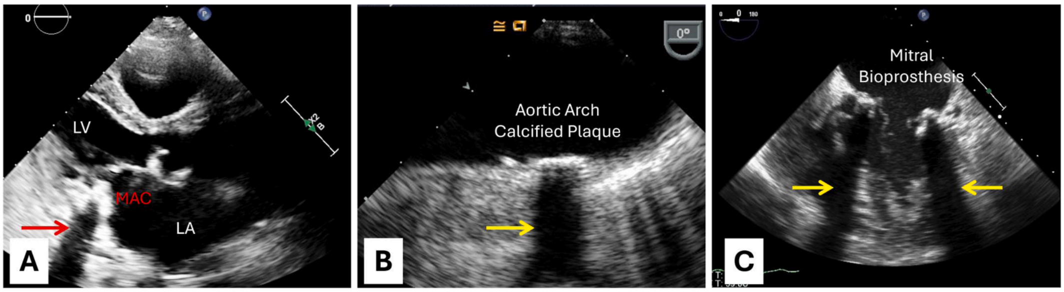

Figure 9 Two-dimensional acoustic shadowing artifacts. **(A)** Two-dimensional TTE parasternal long-axis view of the mitral valve shows shadowing artifact due to mitral annular calcification *(red arrow)*. **(B)** Two-dimensional TEE high-esophageal long-axis view of the aortic arch shows shadowing *(yellow arrow)* behind the calcified atherosclerotic plaque. **(C)** Two-dimensional TEE midesophageal view of the mitral valve shows shadowing artifacts caused by a mitral bioprosthetic sewing ring *(yellow arrows)*. *MAC*, Mitral annulus calcification.

2.6. Acoustic Enhancement

Appearance in image. The structures appear hyperechoic (too bright) distal to the echolucent area, such as a fluid collection.[14] Acoustic "enhancement" is seen distal to fluid-filled structures, such as the gallbladder and liver cysts. Another example of acoustic enhancement is the enhancement of the pericardium distal to the LV in the transgastric short-axis TEE view (Figure 10, Video 10).

Mechanism. An enhancement artifact, also known as negative shadowing, occurs when the uniform attenuation of the ultrasound assumption is violated. It occurs when the ultrasound wave travels through tissue with lower attenuation than the surrounding tissues.[2]

Key Points

- Be cautious when there is a dark or "shadowed" area distal to the strong reflector, such as dense, calcified, or metallic structures and other prosthetic materials. They may prevent full evaluation of tissue structures distal to the offending reflector (e.g., shadowing from a calcified valve may hide vegetations when evaluating for endocarditis).
- Enhancement artifacts are not common findings in cardiac ultrasound imaging; however, they may be observed with pericardial effusion, pleural effusion, ascites, or cysts.

Recommendations

- Change the imaging plane or the angle of the ultrasound beam to avoid acoustic shadowing or acoustic enhancement artifacts.
- Consider TEE or alternative cardiac imaging modalities based on the clinical scenario.

2.7. Speed Displacement (Propagation Velocity) Artifact

Appearance in image. Speed displacement artifacts due to a propagation velocity of less than 1,540 m/s will appear as an image more distal than the true image in the central ultrasound beam.

This artifact typically occurs with a lipomatous interatrial septum. Ultrasound travels through adipose tissue at a slower speed (1,450 m/s) than the assumed speed of human tissue. Due to longer travel time, the image of the lipomatous septum is partly duplicated distal to the true septum. In contrast, the fossa ovalis is almost always spared from lipomatous septum and thus does not exhibit this artifact (Figure 11, Video 11). Ultrasound propagation through the silicone ball in a Starr-Edwards valve prosthesis provides another example of this phenomenon.[19,20]

Mechanism. Speed displacement artifact, also known as propagation velocity artifact, occurs when the assumption of uniform speed of the ultrasound waves in tissue is violated. It is characterized by

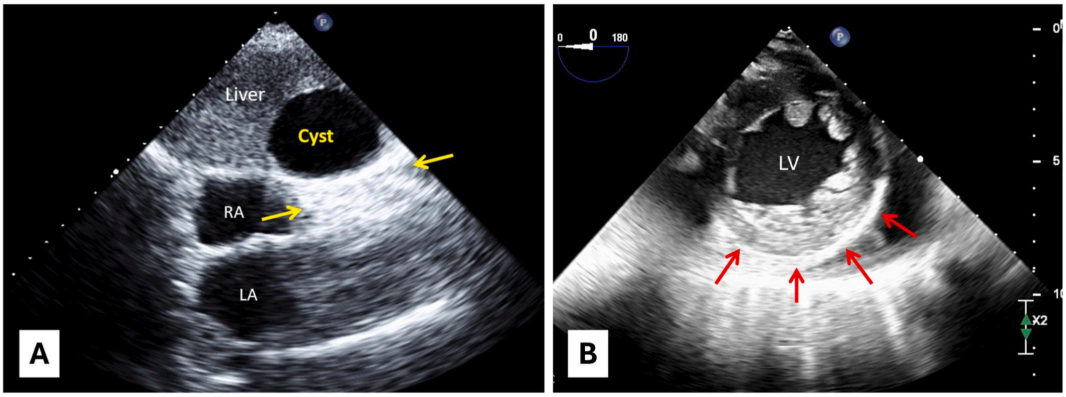

Figure 10 Two-dimensional acoustic enhancement. **(A)** Two-dimensional TTE off-axis subcostal view shows an example of an acoustic enhancement artifact *(yellow arrows)* caused by a liver cyst. **(B)** Transgastric short-axis TEE view of the left ventricle demonstrating acoustic enhancement of the pericardium in the far field *(red arrows)*. *RA*, Right atrium.

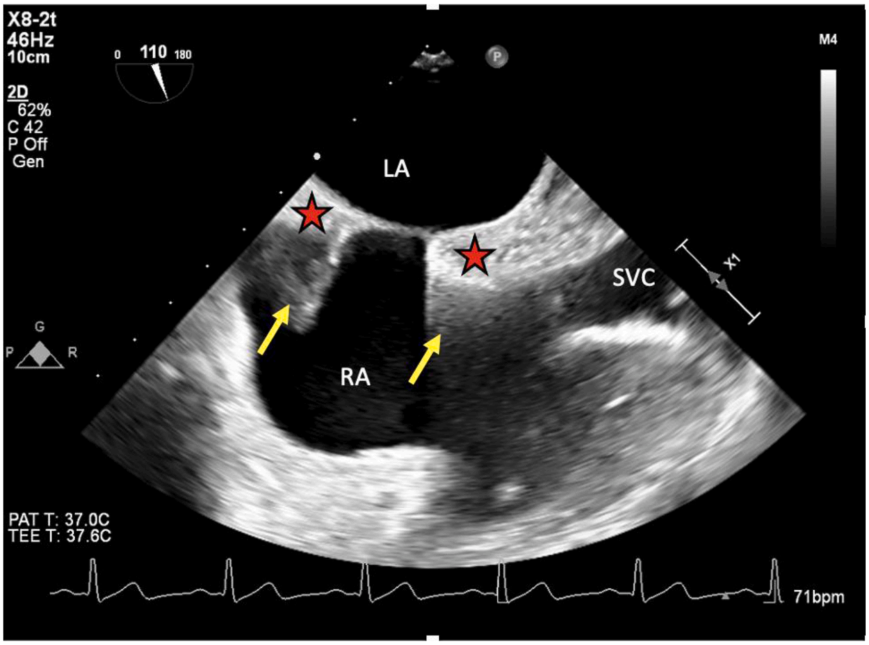

Figure 11 Speed displacement (propagation velocity) artifact. Two-dimensional TEE midesophageal view at 110° demonstrating lipomatous septum of the interatrial septum *(red stars)*. Because of a significant difference in the propagation velocities between the fat (1,450 m/s) and the blood pool (1,540 m/s), the machine misinterprets the distance of the image and generates an image more distal than the true image of the interatrial septum *(yellow arrows)*. The fossa ovalis is spared from fat, and there is no false image in that region. *RA*, Right atrium; *SVC*, superior vena cava.

misrepresentation of position and/or size of a structure. This occurs because the actual speed in certain tissues, such as fat, bone, calcified tissues, or certain artificial materials (e.g., silicone), differs from the assumed speed of sound in those tissues. Consequently, the ultrasound system's assumption of constant ultrasound speed in human tissue is violated.

Key Points

- If the propagation speed through a structure is less than the assumed propagation speed of 1,540 m/s, the structure will be placed farther from the transducer than it really is and will appear to be larger.
- Conversely, if the propagation speed is greater than the assumed propagation speed of 1,540 m/s, the structure will be placed closer to the transducer than its true position.

Recommendations

- Recognize that minimizing this artifact is difficult or nearly impossible and identify the anatomic scenarios in which this artifact is most likely to occur.
- Be aware that misalignment of structures and/or measurement errors may occur.

3. TWO-DIMENSIONAL IMAGING ARTIFACTS IN LATERAL DIRECTION

Artifacts in the lateral direction appear lateral to the real structure on the ultrasound image and include refraction artifacts, beam width artifacts, and side lobe artifacts.

3.1. Refraction Artifact

Appearance in image. This artifact manifests as a duplicate false image positioned laterally to the real structure. The refraction artifact is generally less bright and typically shows the anatomic structure only partially. Refraction artifacts are common in parasternal and subcostal imaging planes. Classic refraction artifacts include double images of the aortic valve, mitral valve, or LV in the short-axis view (Figure 12, Video 12).

Mechanism. Refraction artifact occur when 2 ultrasound machine assumptions are violated: Ultrasound waves travel along a straight path and each transmitted ultrasound beam has a single round trip. It is also called double image or lens artifact, occur when the ultrasound beam hits an object obliquely such as pleural or pericardial surfaces, costal cartilages, or fascial structures, which act like a lens and bend the ultrasound beam toward the anatomic object (such as the aortic valve). The bent ultrasound beam is then reflected from the anatomic object and travels back to the transducer along the bent pathway. Because the ultrasound system assumes a straight pathway, it projects the artifactual image to the side of the true object (Video 13).[1]

Key Points

- Refraction artifacts should be suspected when duplicated structures appear partially, are less echogenic, and are located lateral to the true structure.
- In refraction artifacts, the artifactual structures may be misinterpreted as pathological findings.
- Refraction artifacts can obscure the full evaluation of true anatomic structures.

Recommendations

- Utilize alternative imaging windows or planes.
- Adjust the imaging angle to avoid objects acting like a lens.

3.2. Beam Width and Slice Thickness Artifacts.

Appearance in image. The beam width and slice thickness artifacts may be misinterpreted as true masses, leading to unnecessary diagnostic procedures (Figure 13). A pacemaker/intracardiac defibrillator lead may appear in the incorrect cardiac chamber that is lateral to the true chamber location.[21,22]

Mechanism. Ghost images of highly reflective objects positioned outside the imaging plane but in the elevational width (also called slice thickness artifact) or in the poor-resolution lateral width of the ultrasound beam are erroneously positioned within the center of the beam.[1,2] Both artifacts violate the assumption that ultrasound echoes are generated only from reflectors located within the main lobe of the ultrasound beam. The beam width artifact is caused by the inherent properties of the hourglass appearance of the ultrasound beam, which becomes wider and less focused as it travels away from the transducer and focal zone. This widening results in a reduced ability to distinguish between structures located side by side (lateral resolution), potentially leading to overlapped images. The slice thickness artifact occurs because of the limited thickness of the ultrasound beam in the elevational plane.[6]

Key Points

- Beam width and slice thickness artifacts are related to the physical dimensions and properties of the ultrasound beam displayed in a single thin tomographic plane.
- They can cause off-axis echoes (ghost echoes) to appear within the image or may cause overestimation of the size of structures.
- The ghost echoes mostly appear in the echo-free cavities of the atria and/or ventricles.

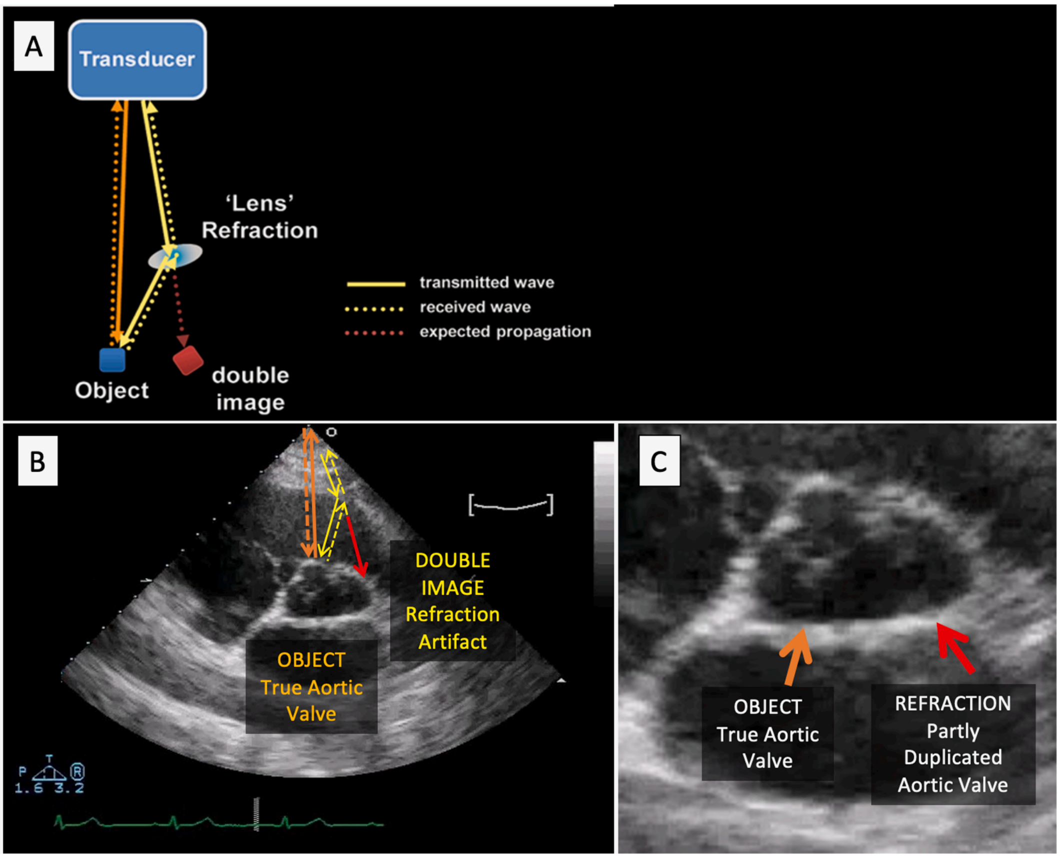

Figure 12 Two-dimensional imaging refraction artifact. **(A)** Schematic explanation of how the refraction artifact is generated. The ultrasound waves originating from the transducer are directed through an object acting as a lens and refracted toward the respective cardiac object and back. The result is a duplication of the object in the initial beam direction (the double image). **(B)** Refraction artifact on the TTE short-axis view at the level of the aortic valve appears as a partly duplicated aortic valve to the side of the true aortic valve. **(C)** Magnify view of the true aortic valve (*orange arrow*) and refraction artifact shown as partly duplicated aortic valve (*red arrow*).

Recommendations

- Adjust the focal zone to the depth of interest.
- View the structure from different angles and windows.
- Decrease the gain setting.
- Increase the probe frequency to narrow the focal zone and reduce unwanted echoes.

3.3. Side Lobe Artifact. **Appearance in image**. Side lobe artifacts often occur near highly reflective surfaces or objects. A common side lobe artifact happens when a calcified sinotubular junction results in a curvilinear artifact in the ascending aorta, mimicking an aortic dissection flap. Also, in the parasternal long-axis view, a strongly reflective pericardium results in a linear side lobe artifact in the LA. Another example is the appearance of biatrial shadows in the far field of an apical 4-chamber view (Figure 14, Video 14).[1,23]

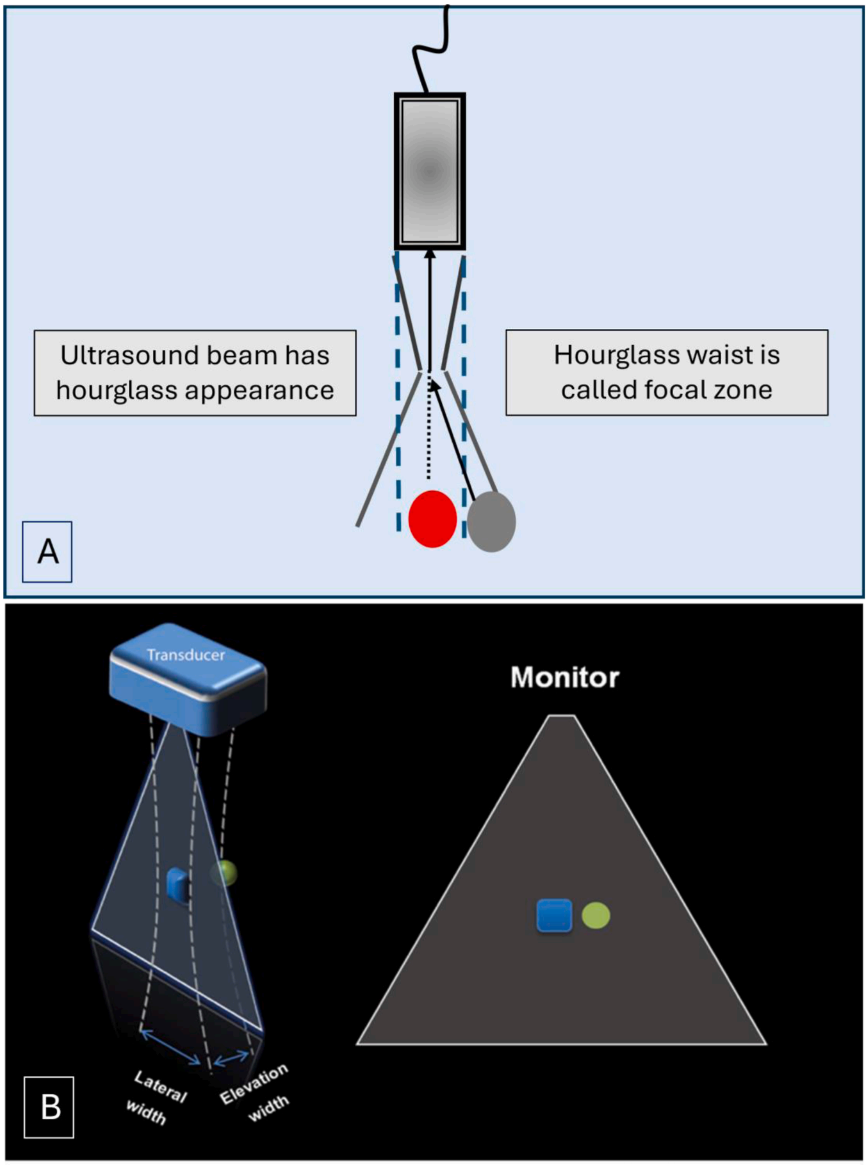

Figure 13 Two-dimensional imaging beam width artifact. **(A)** Schematic explanation of ultrasound beam appearance with focal zone. **(B)** Schematic explanation of the genesis of the beam width artifact. The beam width artifact occurs when the ultrasound beam is reflected from a hyperreflective object positioned outside the imaging plane, but in the elevational width (also called slice thickness artifact) or poor-resolution lateral width of the ultrasound beam and the ultrasound system assumes the object is located within the single thin imaging plane.

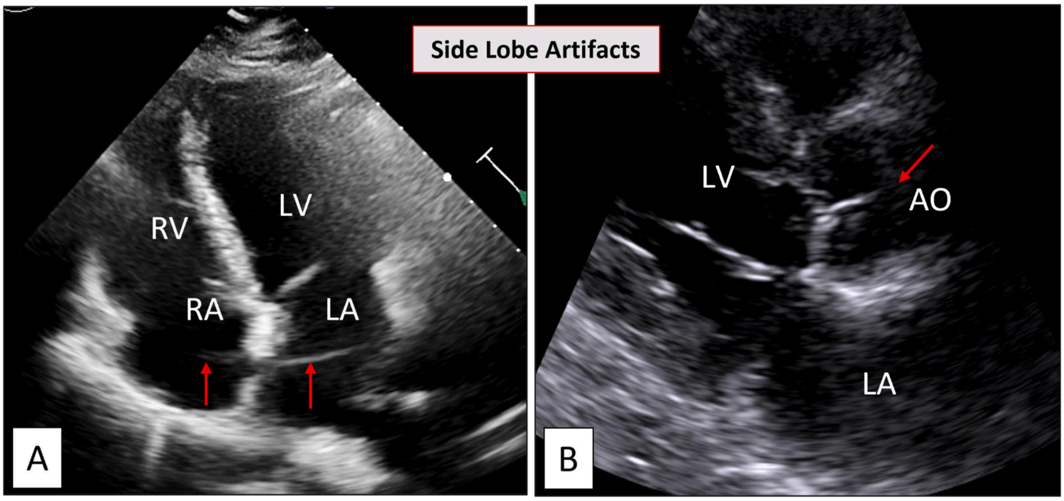

Figure 14 Two-dimensional imaging side lobe artifacts. **(A)** Side lobe artifact in the atria in the apical four-chamber TTE view *(red arrows)*. **(B)** Side lobe artifact of the calcified aortic valve *(red arrow)* in the parasternal long-axis TTE view. Corresponds to Video 14. *AO*, Aorta; *RA*, right atrium; *RV*, right ventricle.

Mechanism. Side lobe artifacts occur when 2 ultrasound machine assumptions are violated: (1) ultrasound is uniformly attenuated by the tissue and (2) echoes originate only from the main (central) ultrasound beam (Video 15). Most of the emitted ultrasound energy is concentrated in the center, forming the main beam, with smaller amounts of energy directed toward the sides of the main beam. Side lobe artifacts arise when a small portion of the ultrasound beam emits laterally and encounters a strong reflector adjacent to the main lobe, which the ultrasound system interprets as if originating from the main lobe.

Key Points

- Side lobe artifacts can mimic dissection flaps, intracardiac mass, or thrombus.
- This artifact appears linear or arch shaped, symmetric on both sides of the echogenic reflector, and does not spare the borders of the imaged structure.
- They may cross anatomical boundaries (e.g., appearing to pass through cardiac or vascular walls), which true structures do not.

Recommendations

- Lower the gain settings.
- Switch to harmonic imaging.
- Change the transducer angle or use a different window.

4. ARTIFACTS IN SPECTRAL DOPPLER IMAGING

Doppler echocardiography is the basis of noninvasive hemodynamic assessment of the cardiovascular system. The ultrasound system measures the Doppler frequency shift, that is, the difference between the transmitted and received frequencies of the ultrasound wave backscattered by a moving target. The Doppler equation is then used to convert this frequency shift into the velocity of a moving target:

$$V = \frac{\Delta F * c}{2F_0 * \cos(\theta)}$$

where V is the velocity of the moving target (which is red blood cells in hemodynamic assessment) ΔF is the Doppler frequency shift, c is the ultrasound velocity in the tissue (assumed to be 1540 m/s), F_0 is the transmitted frequency, and cos (θ) is the cosine of the insonation or intercept angle θ.[6,24] Ideally, the angle θ should be as close to 0° (that is, coaxial to the moving target) to obtain the true maximum blood flow velocity.

Artifacts may be seen with all 3 forms of Doppler imaging, including pulsed-wave Doppler (PWD), continuous-wave Doppler (CWD), and color Doppler (a form of PWD).[25] Pulsed-wave Doppler uses a single ultrasound crystal to send short pulses of ultrasound at discrete time intervals (referred to as the pulse repetition interval) and then measures the frequency shifts from a discrete user-specified region of interest along the ultrasound beam (referred to as a gate or sample volume). However, it is prone to aliasing, which is an inaccurate representation of velocity and direction.

Continuous-wave Doppler utilizes 2 ultrasound crystals, with one continuously sending and the other continuously receiving Doppler signals. The advantage of CWD over PWD is the ability to measure high velocities without signal aliasing. Continuous-wave Doppler cannot locate the depth (along the scan line) at which the highest frequency shift (or velocity) is encountered.

4.1. Overgain and Undergain on Spectral Doppler

The Doppler gain function is used to amplify the returning Doppler signals. Doppler gain should be adjusted to ensure the clearest possible spectral recordings.

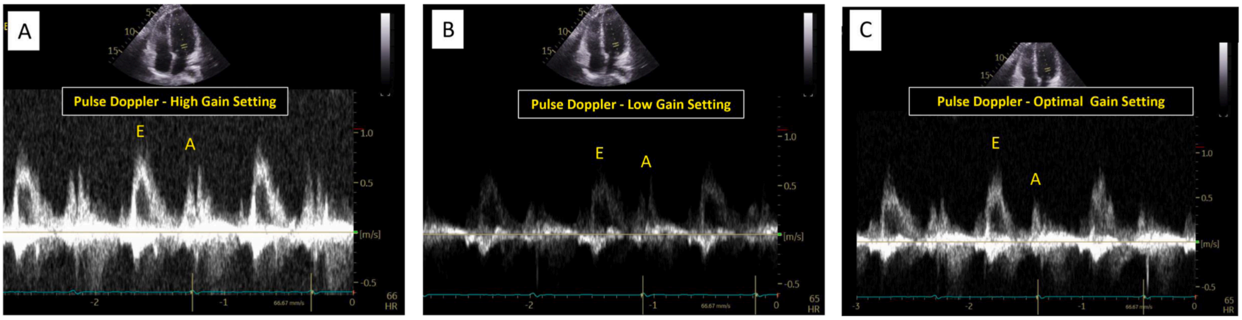

Figure 15 Spectral Doppler overgain and undergain. PWD study of mitral valve inflow. **(A)** High gain setting. **(B)** The same figure captured with a low gain setting. **(C)** The same figure captured with an optimal Doppler gain setting. *E* and *A* indicate peak early and late diastolic modal velocity of mitral inflow.

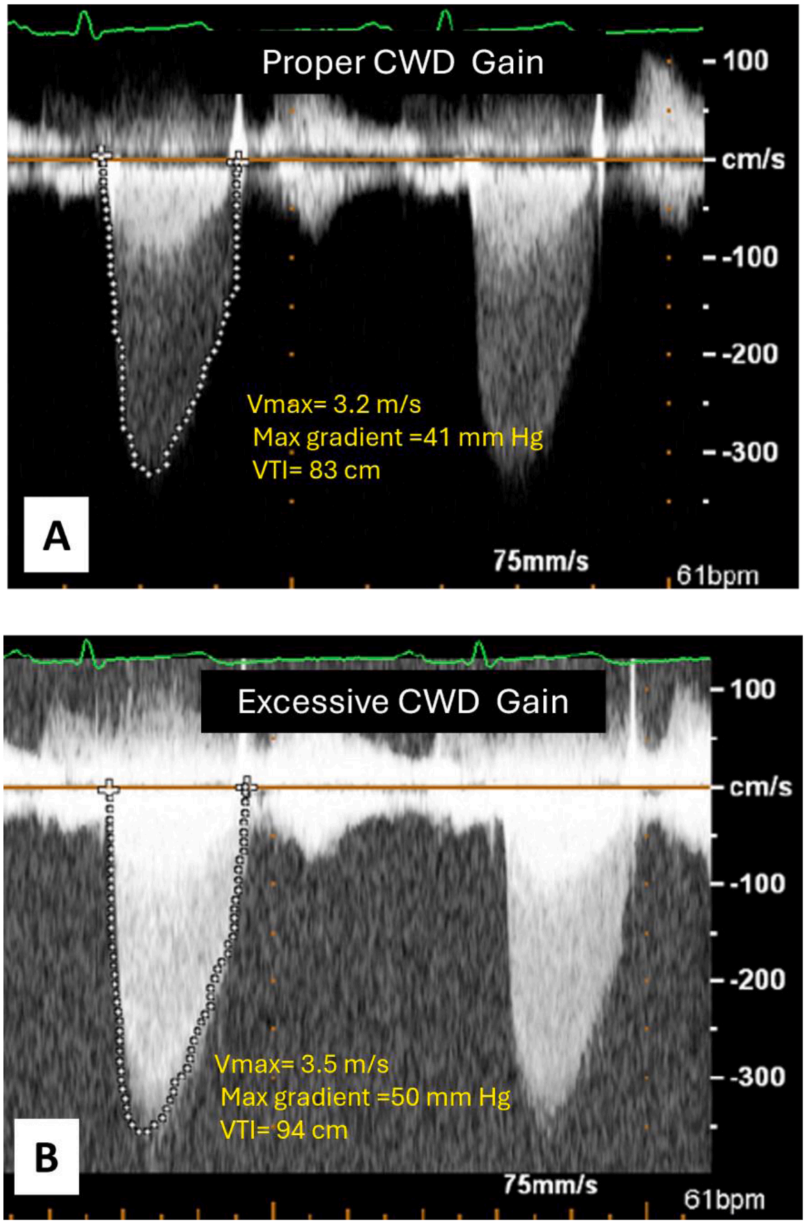

Figure 16 Spectral Doppler overgain. CWD study of the aortic valve. **(A)** Proper CWD Gain. **(B)** Excessive CWD gain resulting in falsely elevated peak aortic valve velocity. *Vmax*, Maximum velocity; *VTI*, velocity-time integral.

Appearance in image. Overgaining can cause excessive noise and a brighter signal, while undergaining can result in a less bright signal and missing low-amplitude information (Figure 15). The measured peak velocity of a jet of tricuspid regurgitation (TR) or aortic stenosis may be falsely elevated due to an overgained CWD signal (Figure 16, Video 16).

Mechanism. Overgaining is caused by excessive amplification of Doppler signals. In contrast, the undergain phenomenon is caused by insufficient amplification of the Doppler signals.

4.2. Spectral Wall Filter

Appearance in image. Lower filter settings facilitate the visualization of low-velocity signals near the baseline. A high-pass filter eliminates the low-velocity flow signals close to the zero baseline. Figure 17 demonstrates the effect of low and high wall filter settings on Doppler velocity recordings.

Mechanism. When measuring blood flow velocities (high-velocity, low-amplitude signals), wall filters are used to eliminate low-velocity, high-amplitude signals arising from cardiac chamber walls. In contrast, when using tissue Doppler imaging, high-velocity filters are used to suppress blood velocities and enhance visualization of low tissue velocities.

Key Points

- Overgain spectral Doppler can overestimate Doppler velocity measurement, leading to unnecessary diagnostic or therapeutic interventions.
- Low-gain spectral Doppler settings can result in missing important low-amplitude information.
- Wall filter settings are important when assessing velocities in low-flow states to exclude irrelevant low-velocity signals (from valves or walls) and make time interval measurements more accurate.

Recommendations

- Adjust the Doppler gain to obtain the true, distinct, smooth spectral envelope. The densest portion of the spectral Doppler signal should be measured.
- Adjust the wall filter to display the start and end of the flow signal of interest.

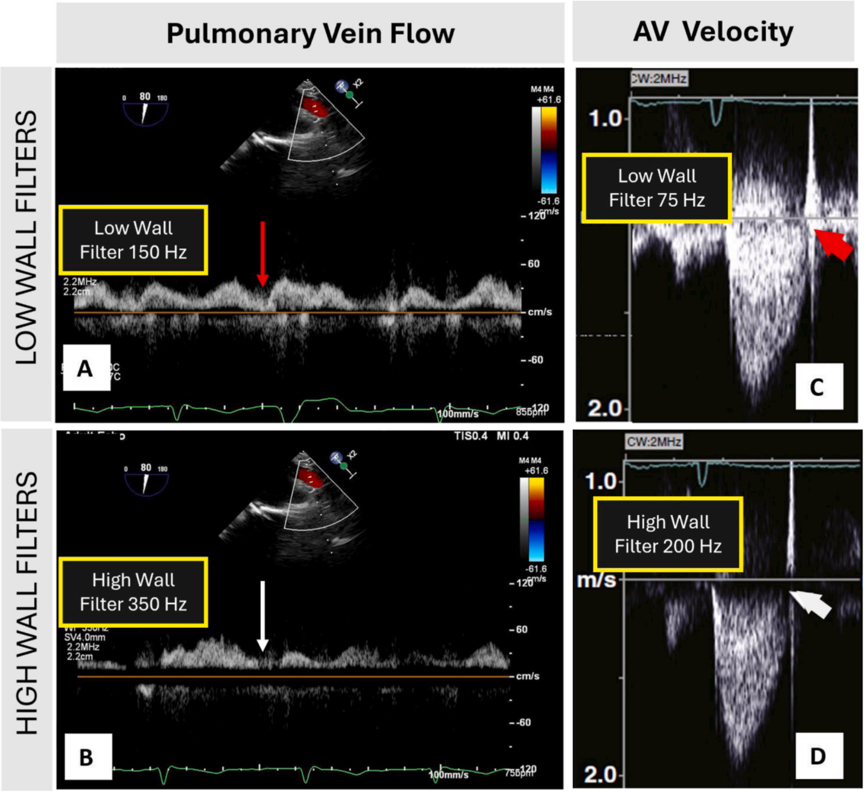

Figure 17 Spectral Doppler wall filter. **(A, B)** two-dimensional TEE midesophageal view, spectral Doppler study of the left upper pulmonary vein. **(A)** Application of a low wall filter (150 Hz, *red arrow*) to delineate a clear spectral Doppler envelope of pulmonary venous flow, showing both systolic and diastolic phases. **(B)** Applying a high wall filter (350 Hz, *white arrow*) eliminates the critical information essential for a complete assessment, as the low-velocity flow components are suppressed. **(C, D)** CWD recordings of aortic valve flow using low (75 Hz, *red arrow*) and high (200 Hz, *white arrow*) filters. Lower filter settings show extension of velocity signals to the baseline, making time interval measurements more accurate. High filters eliminate the low-velocity flow signals. *AV*, Aortic valve.

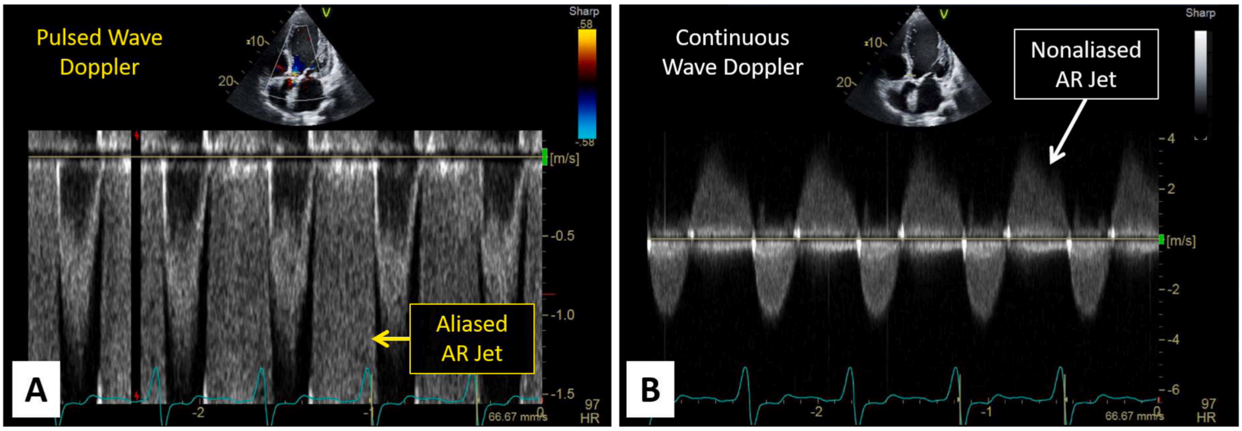

Figure 18 Spectral Doppler aliasing. **(A)** Shows an aliased LVOT PWD signal caused by AR. The ambiguous Doppler signal displayed in diastole *(yellow arrow)* wraps around the baseline, which precludes accurate measurement of maximal velocity because the peak AR velocity exceeds the Nyquist limit, which is equal to one half the pulse repetition frequency. **(B)** Aliasing is eliminated by using CWD (*white arrow*). The AR signal is displayed appropriately above the baseline (flow toward the transducer).

4.3. Velocity Scale Error/Aliasing

Aliasing is the inability to accurately represent the velocity and direction of blood flow. Aliasing occurs with both PWD and color Doppler imaging. The highest velocity that can be accurately measured is referred to as the Nyquist limit, which is equal to one-half of the pulse repetition frequency (PRF), representing the sampling frequency of the transducer.

Appearance in image. With spectral Doppler aliasing, the highest velocities are “cut off” and displayed reversely in the opposite direction.[26] Figure 18 demonstrates aliased PWD and nonaliased CWD recordings from the left ventricular outflow tract (LVOT) in the presence of aortic regurgitation (AR).

Mechanism. Aliasing occurs when the velocity of a moving object (e.g., red blood cell) exceeds the Nyquist limit. Aliasing is commonly seen with PWD when blood flow velocities are above 1.5 to 2 m/s.[1] To determine the Nyquist limit, the ultrasound system compares the pulse repetition period of the transducer (the inverse of PRF) to the time of flight from the transducer to the sample volume and back. The more distal the sample volume, the lower the maximum Nyquist limit that can be set by the ultrasound system. The ultrasound system uses a combination of the Nyquist and Doppler equations to determine the maximum Nyquist limit (aliasing *V*max):

$$\text{Nyquist Limit} = \frac{\text{PRF}}{4 * F * \cos(\theta)} * c$$

where c is ultrasound velocity (1,540 m/s) F is the emitted frequency, and θ is the angle of insonation.

Pulsed-wave Doppler has the advantage of measuring blood flow or tissue velocities from a specific location in the heart (sample volume).[27] Color Doppler aliasing is elaborated further in the color Doppler artifacts section of the document.

Key Points

- Aliasing creates confusion about the Doppler flow direction and precludes accurate measurement of maximal velocity.
- Aliasing results in misinterpretation of velocities if it remains unrecognized.

Recommendations

To avoid aliasing,

- Shift the baseline to the opposite direction of flow.
- Decrease the transducer frequency.
- Decrease the sample volume depth if possible (and increase PRF).
- Switch to CWD (but this leads to range ambiguity, that is, inability to determine the location at which the velocity signals are recorded).
- Switch to high PRF mode (HPRF), if available on the ultrasound system (this increases the number of sample volumes). However, range ambiguity may occur with HPRF since multiple sampling sites are present along the ultrasound beam; one cannot be certain at which location peak velocities were found.

4.4. Noncoaxial Intercept Angle Doppler Artifact

Appearance in image. A noncoaxial intercept angle Doppler artifact has no specific appearance other than underestimating the true velocity compared to other recordings. The aortic valve peak velocity is underestimated when the Doppler beam is not coaxial with the aortic flow. This is the reason why aortic stenosis recordings should be obtained from multiple windows.[28] This artifact occurs with both PWD and CWD (Figure 19).

Mechanism. Based on the Doppler equation, when the ultrasound beam and blood flow direction are coaxial ($\theta = 0°$), $\cos(\theta)$ is 1 and maximum velocity is recorded. As the Doppler intercept angle (between the ultrasound beam and the blood flow, θ) increases from 0° to 90°, the cosine of θ decreases from 1 to 0. This leads to a progressive decrease in the maximum velocity measured (relative to the actual velocity) until no velocity is detected when the angle is 90°.

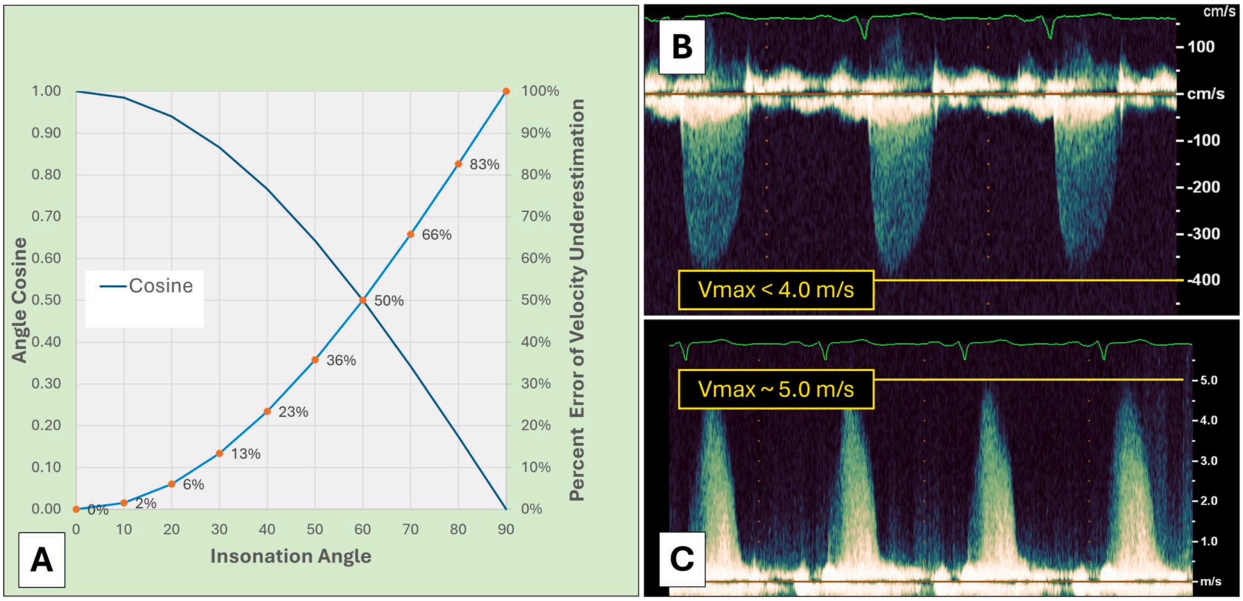

Figure 19 Spectral Doppler insonation angle error. **(A)** Spectral Doppler insonation angle error is inversely related to the cosine of the insonation angle (θ). When the angle increases from 0° to 90°, the cosine decreases from 1 to 0. The recorded velocity is maximal at 0°, is significantly lower when the insonation angle is 60° or greater, and when the probe is perpendicular to the flow ($\theta = 90°$) no velocity is recorded. **(B)** CWD recording from the apical five-chamber view underestimates the degree of aortic stenosis compared with **(C)**, which demonstrates recordings from the right parasternal window having a more coaxial insonation angle to aortic flow.

4.5. Spectral Broadening/Transit Time Effect

Appearance in image. Spectral broadening may appear as a "fill-in" of the area between a flow velocity curve and the baseline due to the varying velocity of the moving target within the sampling area. The transit time effect also blurs the spectral Doppler curve.

For instance, when evaluating aortic stenosis, the maximum velocity is measured at the outer edge of the brightest signal; fine linear signals at the peak of the curve are due to transit-time effects and should not be included in measurements. The fine linear signals of the Doppler signal may be referred to as the beard, while the true flow velocity outline is referred to as the chin. Figure 20 demonstrates the broadening of the LVOT PWD signal.

Mechanism. This artifact occurs because not all red blood cells move at the exact same speed or in the exact same direction in the sample volume. As the target moves through the beam, it gives back a slightly different Doppler frequency within the sampling area, which is called the transit time effect. The transit time effect is an important cause of spectral broadening. It blurs the spectral Doppler curve and broadens the spectral signal on the Doppler display as originally described by Liv Hatle.[29] The spectral broadening occurs particularly due to turbulent blood flow when a range of red blood cell velocities is sampled at once, causing the spectral display to widen. This error is dependent on the angle of insonation and the velocity of blood flow.

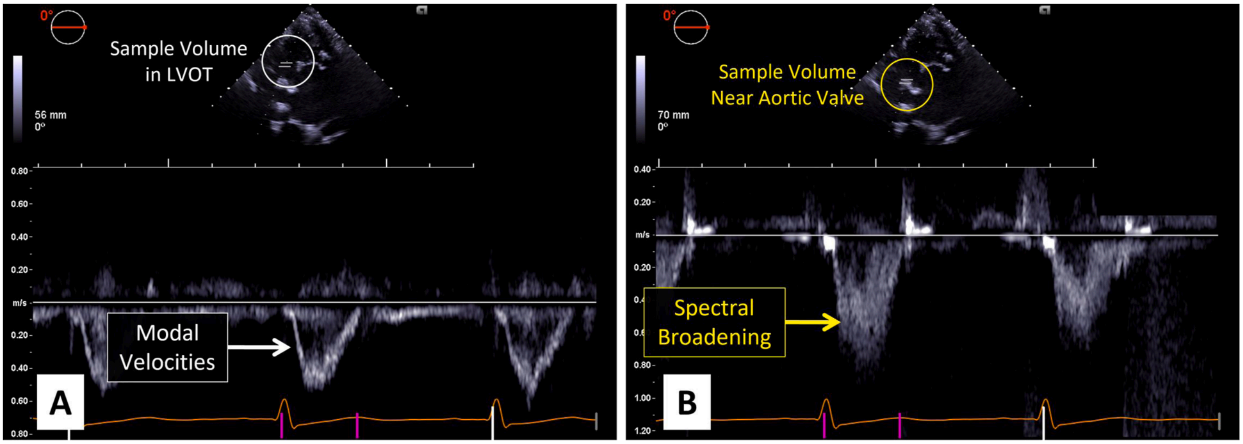

Figure 20 Spectral Doppler broadening. **(A)** PWD LVOT recording with appropriate modal velocities (*white arrow*). **(B)** Spectral broadening of the LVOT signal prevents accurate LVOT velocity measurements (*yellow arrow*).

Key Points

- Clinically, an excessive intercept angle is one of the most important potential errors in measuring true velocity. The underestimation error is only 6% with an angle of 20° but increases to 50% at a 60° angle.
- Identification of peak velocity can be challenging when a spectral broadening artifact occurs.

Recommendations

- Adjust the transducer to change the imaging angle or use alternative imaging windows and realize that the highest velocity will be recorded when the intercept angle is as small as can be achieved.
- Use a nonimaging (pulsed echo Doppler flowmeter) transducer from multiple windows, as its footprint is small and may accommodate windows that are less accessible by imaging transducers.
- Focus on the densest portion of the Doppler signal (modal velocity) to avoid the spectral broadening artifact.

4.6. Spectral Doppler Beam Width Artifact

Appearance in image. In this artifact, adjacent flow signals superimpose into 1 Doppler waveform (Figure 21). Doppler beam width artifact occurs with simultaneous recordings of the AR and mitral stenosis flow velocity patterns, as well as the MR jet contaminating the TR jet, especially when the MR jet is medially directed. However, this mechanism is helpful to record LV inflow and outflow signals simultaneously, which allows the measurement of isovolumic relaxation time.

Mechanism. Beam width artifacts occur frequently with Doppler signals, similar to 2D imaging. They occur since the ultrasound beam has a 3D volume but is displayed in a single tomographic plane. Therefore, blood flow out of the imaging plane but within the 3D volume of the beam is interpreted as if located in the same imaging plane and will be displayed as superimposed signals.[1,2,6]

Key Points

- Beam width artifacts may lead to superimposition of distinct flow jets, complicating accurate assessment of velocities and pressure gradients, such as:
- Overlap of the left ventricular inflow waveform with the aortic regurgitant jet.
- Contamination of the MR jet and left ventricular outflow obstruction waveforms in hypertrophic obstructive cardiomyopathy.

Recommendations

To avoid or mitigate a beam width artifact:
- Limit the sample volume size.
- Avoid far field interrogation.
- Interrogate from different imaging windows.

4.7. Tiger Stripes Artifact

Appearance in image. Tiger striping refers to alternating bright and dark parallel lines on both sides of the Doppler waveform that resemble a tiger's stripes. Tiger stripes may occur with both PWD and CWD recordings. Tiger stripes have been reported with Doppler recordings of native valve regurgitations, flail prosthetic valve

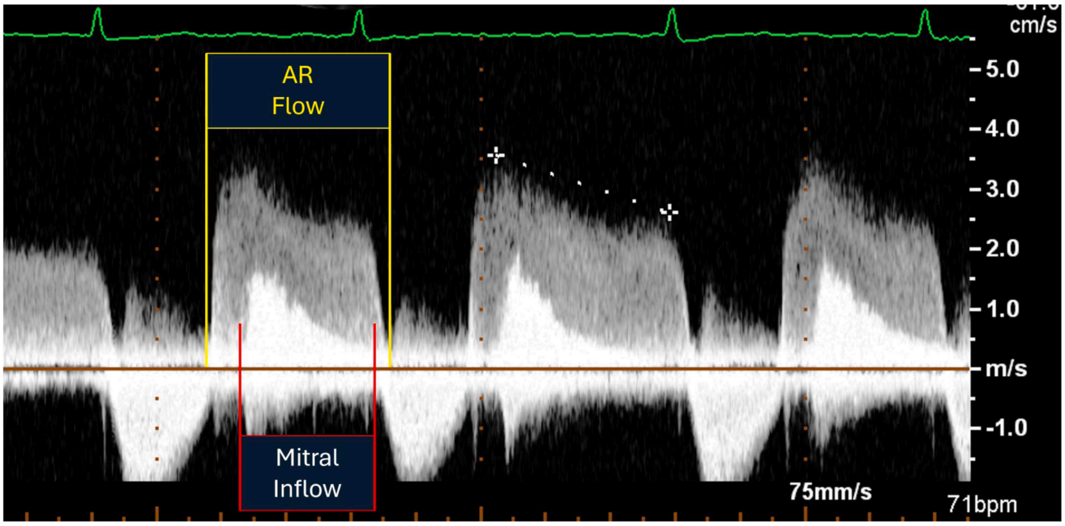

Figure 21 Spectral Doppler beam width artifact. Interrogation of transmitral flow in the TTE apical four-chamber view. The less dense signal (between *yellow lines*), which is the aortic regurgitant flow projected onto the mitral inflow (between *red lines*), is explained by the beam width artifact.

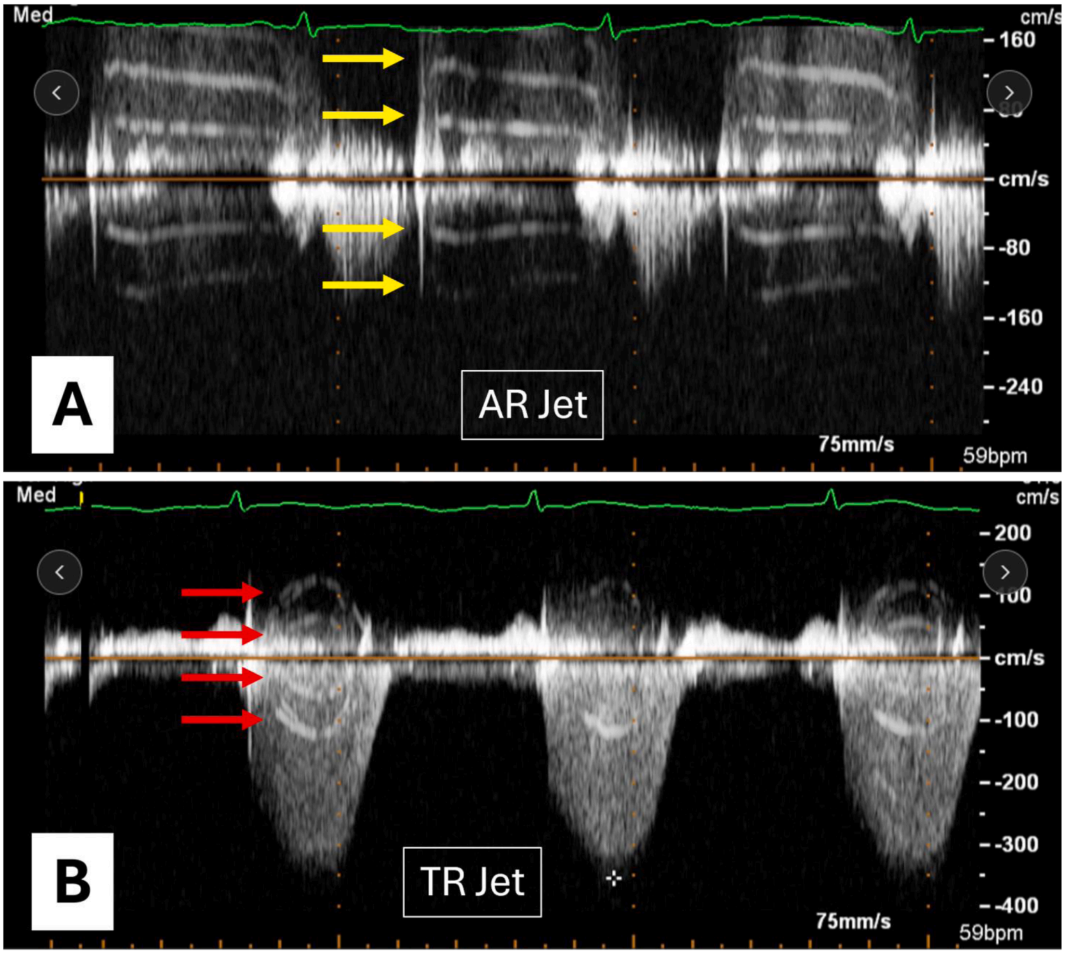

Figure 22 Tiger stripes artifacts. Two-dimensional TTE CWD imaging of the aortic valve **(A)** and the tricuspid valve **(B)**. The repetitive bandlike images *(arrows)* are noted on both sides of the baseline because the emitted ultrasound beam hits an oscillating intracardiac structure. The first band closest to the baseline represents the lowest (fundamental) frequency of the oscillating structure, while the other bands represent harmonic overtones.

leaflets, intracardiac mobile masses such as ruptured papillary muscle, and Lambl's excrescences, and even with pacemaker leads (Figure 22).

Mechanism. Tiger stripes artifact occurs when the emitted ultrasound beam encounters an oscillating intracardiac structure, resulting in ladder-like bands nearly parallel to the baseline. The first band closest to the baseline represents the lowest (fundamental) frequency of the oscillating structure, while the second band represents the second harmonic frequency, and so on.[30]

4.8. Mirror Image/Spectral Mirroring Artifact

Appearance in image. The Doppler signal appears symmetric with less density on the opposite side of the baseline. Figure 23 demonstrates a mirror image artifact with spectral Doppler recordings of pulmonary venous flow on TEE.

Mechanism. The mirror image artifact in spectral Doppler has 2 mechanisms: ultrasound systems' misinterpretation of the received signals or with the interrogation of a flow at a near-perpendicular angle. It may occur when a flow is near a highly reflective surface, such as the pleural or pericardial lining.[1,6]

4.9. Double Envelope Doppler Flow Pattern

Appearance in image. The artifact is characterized by a faint duplication of a denser spectral Doppler jet (typically with CWD) as seen in Figure 24. The velocity of the outer duplicated envelope is exactly double the modal velocity of the inner denser envelope (true/actual velocity). A CWD recording across a mitral prosthetic valve may demonstrate a double envelope Doppler flow pattern.

Mechanism. The double envelope Doppler flow pattern is conceptually described as both a reverberation/duplication artifact from a strong reflector occurring in high flow states and a higher Doppler gain. Also, complex fluid mechanics such as wall jet, which is the convergence of mitral inflow and septal wall, has been suggested as a possible mechanism.[31,32] This mechanism was elicited on a completely normal valve by increasing the Doppler gain from 10% to 55%, replicating the artifact and supporting the explanation.

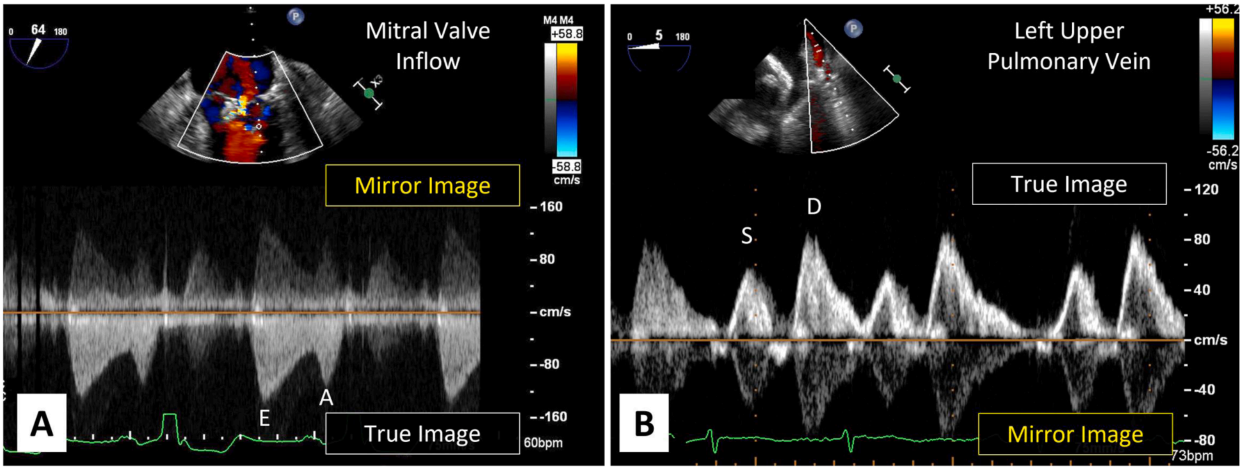

Figure 23 Spectral Doppler mirror image artifact. **(A)** CWD recordings of the mitral valve. **(B)** PWD recordings of flow in the left upper pulmonary vein. Both panels were acquired on TEE and show mirror image signals as labeled. Note that this Doppler artifact is less dense than the true signal. *E* and *A* indicate peak early and late diastolic velocity of mitral inflow and the letters *S* and *D* indicate systolic and diastolic flow in the left upper pulmonary vein.

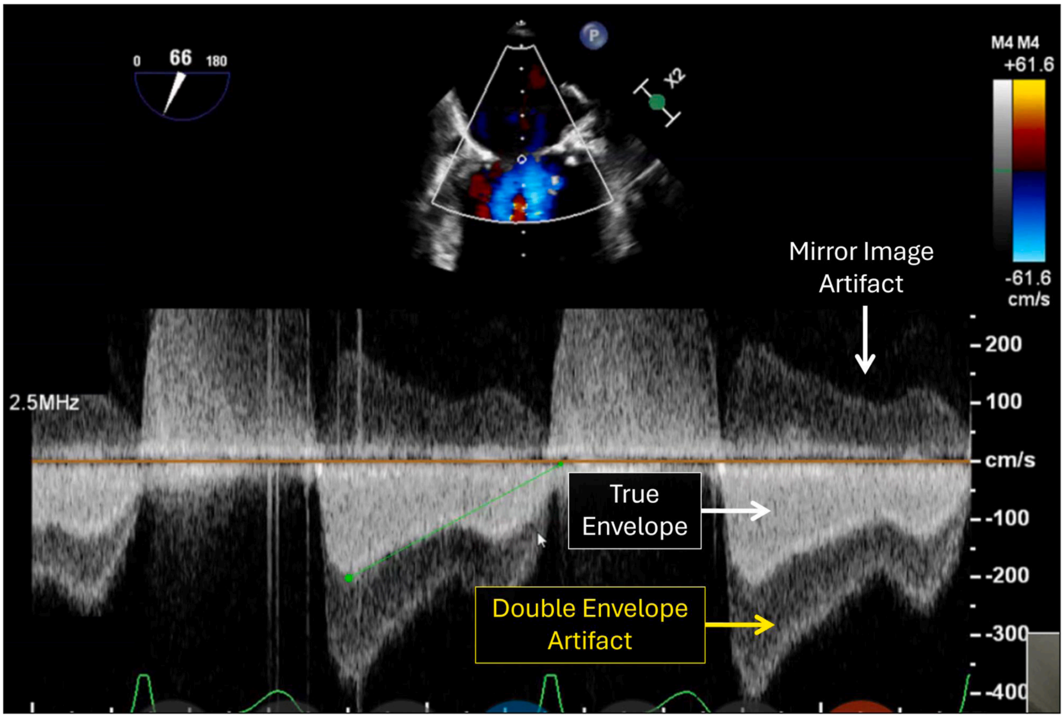

Figure 24 Spectral Doppler double envelope artifact. Two-dimensional TEE study of a calcified mitral valve shows double envelope artifacts as a faint image *(yellow arrow)* on the same side of the baseline as the true spectral envelope (the dense inner tracing, *horizontal white arrow*). Note also the mirror image artifact *(top vertical white arrow)* above the baseline.

A double envelope artifact may occur during the interrogation of a densely calcified mitral valve or a mitral valve prosthesis, particularly when imaged by TEE.

Key Points

- Tiger stripes result from rapid oscillations of structures, such as flail valve leaflets.
- Spectral Doppler mirror image artifacts can lead to erroneous interpretation of flow direction and velocity.
- The double envelope artifact may cause gradient overestimation for native or prosthetic mitral valve assessment, especially by TEE.
- The opening and closing clicks in the Doppler study of the prosthetic valves should be recognized (Figure 25) as the absence of these prominent clicks may suggest prosthetic valve dysfunction.

Recommendations

- Recognize tiger stripes because they may indicate underlying pathology or structural abnormalities, leading one to look for the oscillating structure.
- Reduce the gain and power output and ensure optimal alignment of the Doppler beam with blood flow to avoid spectral Doppler mirror image artifact.
- Decrease the gain and adjust the imaging plane to minimize the double envelope Doppler flow.

5. ARTIFACTS IN COLOR DOPPLER IMAGING

Color Doppler image artifacts can be classified as related to the physics of reflection and refraction (acoustic shadowing, mirror artifact, reverberation, and refraction artifact), ultrasound beam properties (beam width artifact, side lobe artifact), or specific properties of color Doppler image processing (aliasing, blooming). If a color Doppler signal on echocardiography does not make anatomic or physiological sense, one should seek an explanatory artifact similar to physical principles and assumptions that apply to the incident and scattered-frequency-shifted sound waves; hence, similar imaging artifacts can be observed in color Doppler imaging as in 2D and spectral Doppler imaging.[33-37] However, color Doppler artifacts can occur without simultaneous 2D image artifacts and many 2D imaging artifacts are not associated with color Doppler artifacts. Color Doppler imaging can be a powerful tool to help distinguish 2D artifacts from true structures. For example, an apparent mass in the LAA that is otherwise filled with normal flow, as evidenced by color Doppler, is unlikely to be a true mass/thrombus.

Color Doppler imaging utilizes similar physical properties (and flow propagation assumptions) of ultrasound waves to construct images of cardiac flow inside and outside of cardiac structures. Specifically, the PWD principle is used to generate a 2D "color map" of blood flow velocities superimposed on the 2D structural image. The velocity and direction of blood flow in a certain location on the color map are determined by the frequency shift between emitted and received ultrasound "pulses," with the location being determined by the respective pulse transit time.

Due to the same basic principles of PWD, color Doppler is also subject to aliasing. In addition, the generation of a color map requires more computing time as multiple sample volumes along multiple scan lines need to be integrated; hence, temporal resolution in color Doppler imaging is lower. By narrowing the color box to the minimal required size, an acceptable temporal color Doppler image resolution can be obtained. Finally, flow may not necessarily be displayed in the same pixels as 2D structures because of a tissue priority algorithm that is used by ultrasound systems. This also depends on the strength of the respective signals.

5.1. Acoustic Shadowing of Color Doppler

Appearance in image. Acoustic shadowing of color Doppler signal may appear as a pie-shaped hypoechoic or anechoic sector of absent color distal to a strong reflector.[38] Typical examples in clinical practice include prosthetic valves (Video 17), pacemaker/intracardiac defibrillator wires, mitral clips (Figure 26), and dense calcifications. Of note, only the sewing rings and struts of a bioprosthetic valve cause shadowing, whereas the leaflets themselves do not.

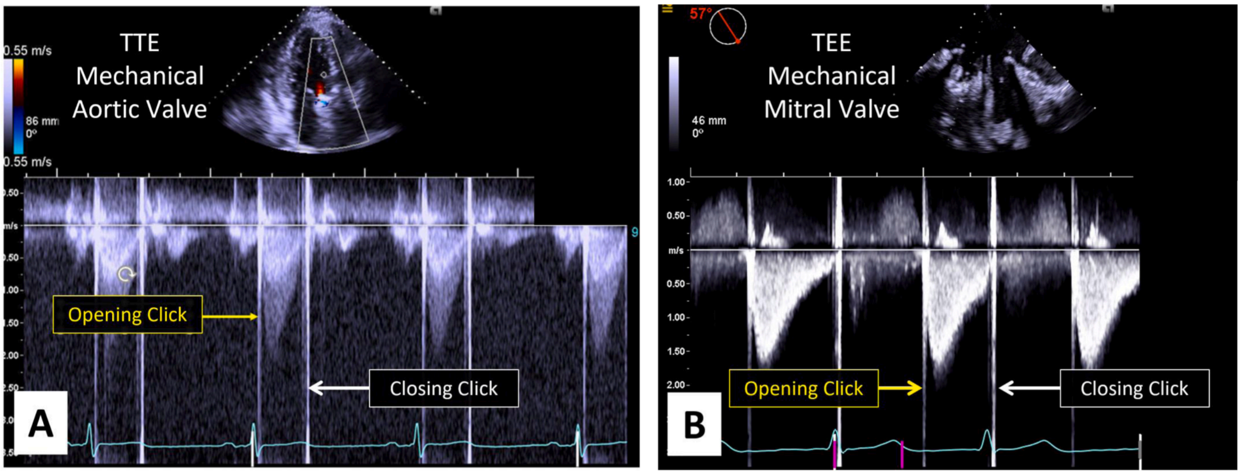

Figure 25 Spectral Doppler click. CWD study of a mechanical aortic valve on TTE **(A)** and mechanical mitral valve on TEE **(B)**. The opening *(yellow arrows)* and closing clicks *(white arrows)* are the *white vertical lines* before and after the mechanical valve flow.

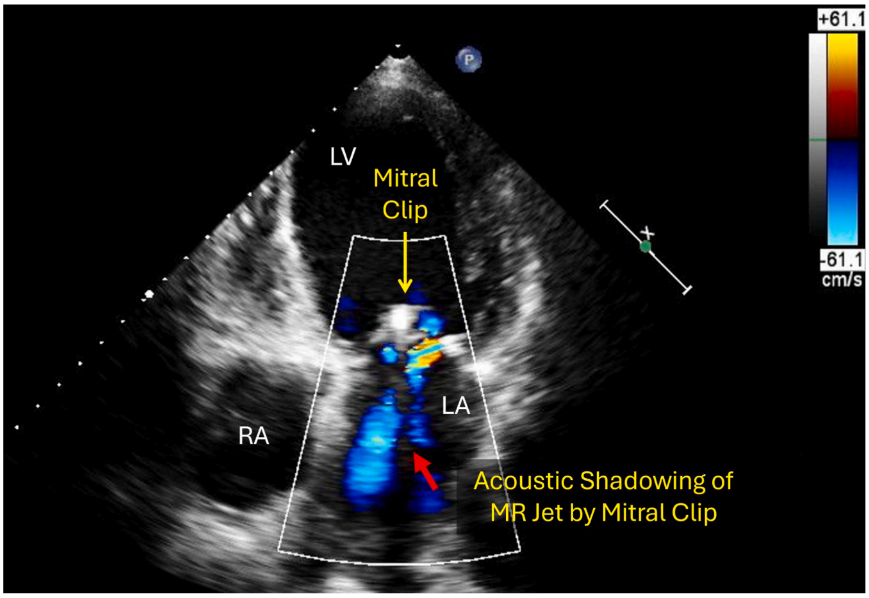

Figure 26 Acoustic shadowing of color Doppler. Two-dimensional TTE apical four-chamber view shows acoustic shadowing *(red arrow)* of the MR jet by a mitral clip *(yellow arrow)*. *LA*, left atrium; *LV*, left ventricle; *RA*, Right atrium.

Mechanism. Acoustic shadowing of color Doppler occurs because a strong reflector (such as calcium or a prosthesis) can prevent the ultrasound Doppler signals from passing through the reflector and result in a shadowed area distally.

5.2. Color Doppler Mirror Artifact

Appearance in image. Mirror artifacts are among the most common color Doppler artifacts.

In patients with calcific aortic stenosis, color Doppler mirror image artifact may simulate a significant mitral regurgitant jet in the LA in the parasternal long-axis view.[39,40] Switching to apical views or examining the mitral spectral Doppler tracing, demonstrating no significant MR, will prove the artifactual nature of the pseudo-mitral regurgitant jet in the LA (Video 18). Another example of color Doppler mirroring in clinical TTE includes a “double-barreled” inferior vena cava from the subcostal window or “double-barreled” aorta from the suprasternal or subcostal window (Figure 27).[16]

Color Doppler mirror artifacts can occur in patients with mechanical mitral valve prostheses. Mirroring of the LVOT flow into the LA on TTE can give the false impression of severe prosthetic mitral valve regurgitation (also known as “pseudo-MR”).[40-42] Pseudo-MR can be

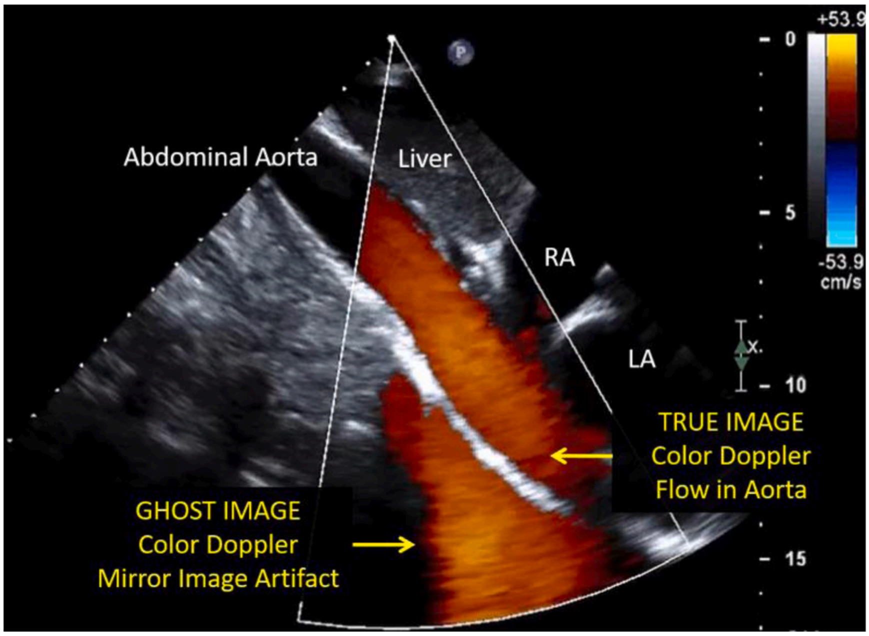

Figure 27 Color Doppler mirror image artifact of the abdominal aorta. Two-dimensional TTE subcostal view with the application of color Doppler demonstrates the long-axis view of the abdominal aorta with the true image of color Doppler flow just beneath the LA and right atrium (RA). A ghost image is seen with a mirror image artifact appearing to show color Doppler flow below the true image of the abdominal aorta. *LA*, left atrium; *RA*, Right atrium.

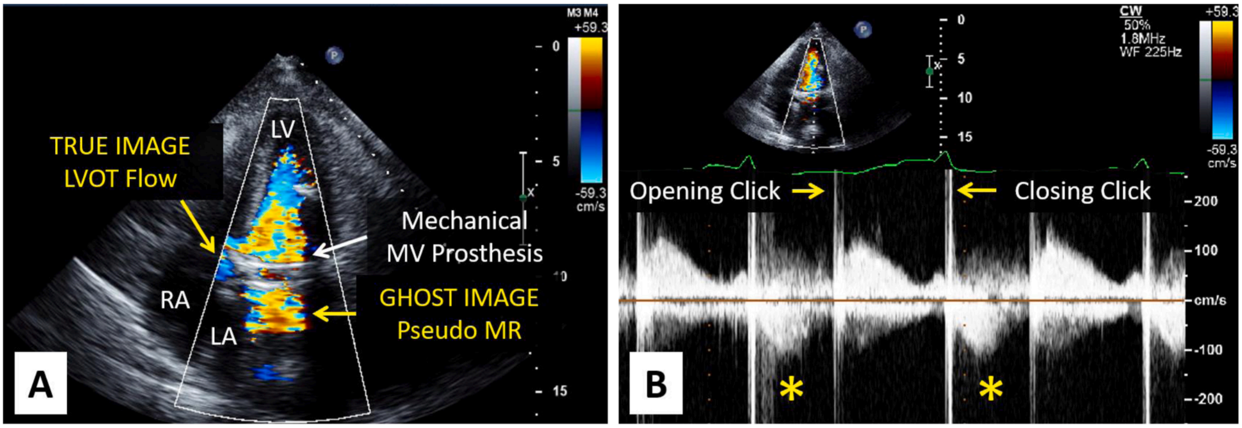

Figure 28 Color Doppler mirror image artifact associated with the mechanical mitral prosthesis. **(A)** Color Doppler study of a mechanical mitral valve prosthesis in the apical four-chamber view demonstrates pseudo-MR due to mirroring of LVOT color Doppler flow. **(B)** CWD imaging in the same study as **(A)** revealed no MR *(yellow asterisks)*, confirming that the jet seen in the LA is a ghost image (pseudo-MR).

distinguished from LVOT flow by examining the PWD velocity waveform, by the absence of a LV proximal flow convergence region and a distance between the prosthesis and the artifactual flow equal to the distance between the mirroring prosthesis and the LVOT on the other side of the "mirror" (Figure 28).

Mechanism. Similar to 2D mirror artifacts, the emitted Doppler "pulses" are mirrored at the level of the reflector and reflected Doppler pulses are misinterpreted by the transducer as originating from distal to the reflector due to the assumption of wave propagation.

5.3. Color Doppler Reverberation and Refraction

Appearance in image. Color Doppler reverberation artifact is seen at a certain distance distal to the actual jet. In a double aortic valve image in parasternal short-axis view (2D refraction artifact), the color Doppler jet will be simultaneously refracted and copied on the artifactual double aortic valve image.

Mechanism. Color Doppler reverberation artifacts are less common than 2D reverberations because Doppler signals themselves are not often strong reflectors. Theoretically, backscattered pulses of a high flux jet (i.e., a flow jet with a high number of scatterers and thus high backscattered Doppler power) could undergo an additional reflection within the body similar to 2D reverberations. A color Doppler refraction artifact on the other hand occurs in the setting of a 2D refraction artifact: when applying color Doppler on the double image (e.g., double aortic valve in parasternal short-axis view), the color Doppler jet will be simultaneously refracted as well.

5.4. Color Doppler Beam Width and Slice Thickness Artifacts

Appearance in image. A prominent MR jet eccentrically directed toward the LA can produce the image of systolic flow in the pulmonary artery (Figure 29).[43,44] Similarly, turbulent LVOT flow in aortic stenosis patients can be mistaken for TR ("pseudo-TR"), although the color jet lacks the typical TR direction and vena contracta. The color Doppler signal is visualized outside the imaging plane.

Mechanism. Blood flowing outside the imaging plane but within the elevation width of the ultrasound beam may be misinterpreted by the system as being within the imaging plane (also known as a slice thickness artifact), potentially leading to diagnostic dilemmas and confusion.[22]

Key Points

- Acoustic shadowing of color Doppler artifact may lead to underestimation of regurgitation severity.
- Color Doppler mirror artifacts, reverberation, and refraction artifacts may erroneously be mistaken for true anatomic flows.
- In the color Doppler slice thickness and beam width artifacts, the origin of the color Doppler flow may be misinterpreted.

Recommendations

- Use an alternative imaging window to visualize the regions in the shadow of reflectors (e.g., TTE imaging of the LA from right parasternal or subcostal 4-chamber views to avoid shadowing by a mitral prosthesis or severe annular calcium).
- In the setting of color Doppler mirror artifacts, reverberation, or refraction artifacts,
  - ○ Use an alternative imaging plane by changing the probe position or angle to avoid artifactual color Doppler signals.
  - ○ Decrease color Doppler gain settings.
  - ○ Suspect color Doppler artifacts when flow jets appear in unusual locations or lack proximal flow convergence or vena contracta.
- In the setting of color Doppler slice thickness and beam width artifacts,
  - ○ Adjust focal zone.
  - ○ Scan the imaging field for out-of-plane flow jet.

5.5. Color Doppler Side Lobe Artifacts/Color Splay

Appearance in image. Color Doppler side lobe artifacts may manifest as linear "arc-like" color Doppler images or symmetric color Doppler images on both sides of a strong color jet. Side lobe artifacts may appear at the vena contracta of significant AR. In patients with an eccentric MR jet, side lobe artifact can be an indirect clue to the presence of significant MR that might otherwise be underestimated and is called color Doppler splay (Figure 30, Video 19).[44,45]

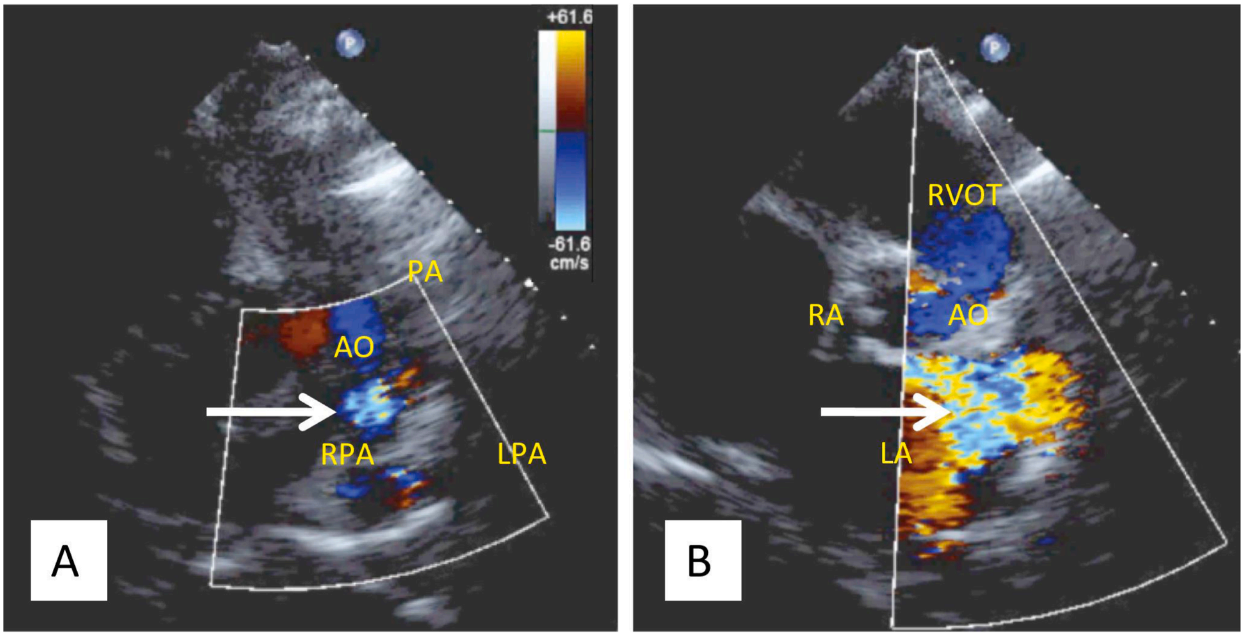

Figure 29 Color Doppler beam width artifact. **(A)** Two-dimensional TTE parasternal short-axis view of the pulmonary artery (PA) and its branches showing unexplained turbulent flow in the PA *(white arrow)*. **(B)** Tilting the probe out of the scanning plane reveals massive MR into the LA *(white arrow)*. The elevational plane width of the Doppler beam accounts for what appears to be turbulent flow in the PA. *AO*, Aortic valve; *LPA*, left pulmonary artery; *RA*, right atrium; *RPA*, right pulmonary artery; *RVOT*, right ventricular outflow tract.

Mechanism. In color Doppler imaging, side lobe artifacts are less prominent, likely because "strong" color Doppler reflectors are not that common. Indeed, in Doppler imaging the low-energy pulses in the side lobes of the ultrasound beam are typically dissipated in the tissue without causing artifacts. Nevertheless, a high flux jet (i.e., a flow jet with high number of scatterers and thus high backscattered Doppler power such as severe MR) could meaningfully reflect low-energy Doppler pulses from the side lobes back toward the transducer to cause a color Doppler side lobe artifact.

5.6. Color Doppler Aliasing

Appearance in image. The aliased color Doppler flow displays as the brightest hue of the color and in the opposite colors of the color map (e.g., from brightest red to brightest blue). Normal LVOT flow can exhibit aliasing if the velocity exceeds the Nyquist limit, as indicated by the color bar (Figure 31). Color Doppler aliasing may also be beneficial for quantifying flow by the proximal isovelocity surface area (PISA) method, which is based on color Doppler aliasing.

Mechanism. Color Doppler is derived from PWD and has similar limitations for measuring velocities that exceed the Nyquist limit. Color Doppler aliasing occurs when the moving targets' frequencies are greater than twice the PRF and create ambiguity in the measurement of the true Doppler frequency shift.

5.7. Color Doppler Blooming and Twinkling

Appearance in image. Blooming artifacts, or "color bleed," relate to the color map extending beyond true anatomical boundaries. It can give a false impression of the flow within soft tissues. A color Doppler "twinkling" noise is a focal, rapidly changing color Doppler signal close to calcifications or devices (e.g., in patients post–transcatheter aortic valve replacement when assessing paravalvular leakage). Spectral Doppler interrogation of the color signal will show a pattern of noise rather than true flow (Figure 32).[2]

Mechanism. Blooming artifacts typically happen in high-gain settings. The twinkle artifact occurs in the proximity of rough reflecting surfaces (calcium, prosthetic devices) and is dependent on the machine setting.[46]

Key Points

- Clinical recognition of color Doppler side lobes is important to avoid misdiagnosing an aortic regurgitant jet for a fistula or abnormal flow.
- Recognizing color Doppler splay artifact can be a marker of significant MR.
- Aliasing in color Doppler imaging is a very common finding and is a useful clue for identifying potentially abnormally high velocities in the heart.
- Color Doppler blooming artifacts can potentially obscure tissue pathology of vessel walls or other structures.

Recommendations

- Decrease the color Doppler gain settings to reduce the color Doppler side lobe artifacts.
- Color Doppler aliasing can be avoided by shifting the baseline, maximizing the velocity scale, decreasing the sector depth, or decreasing the emitted ultrasound frequency.
- To minimize the blooming artifacts and the color Doppler twinkling, the color gain should be adjusted until the signal bleed outside the vessel disappears.
- Increase the wall filter to minimize the blooming artifact.

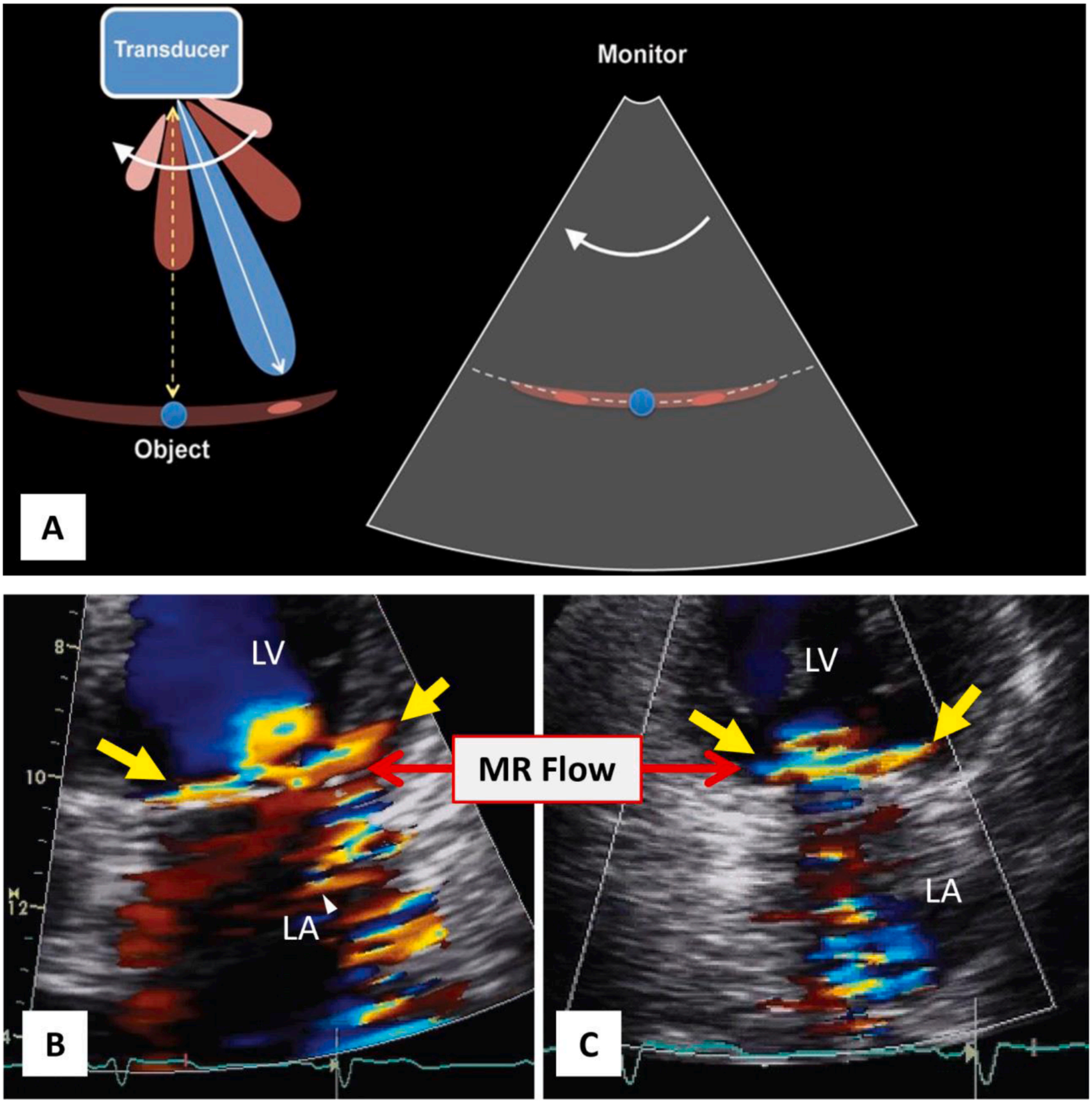

Figure 30 Color Doppler side lobe (splay) artifact. **(A)** Schematic explanation of how color Doppler side lobe artifact (splay artifact) is generated. While interrogating the imaging plane in a radial direction, the Doppler side lobe energy can encounter a jet with high Doppler power. The reflections of side lobe pulses are interpreted as if there is flow originating from the direction in which the transducer is aimed (central beam direction). As the ultrasound beam sweeps the image through the high-flow signal, the side lobes as well as the main lobe of the color Doppler beam are imaged as a linear "arclike" artifact of color Doppler on both sides of the higher power jet. **(B)** Two-dimensional TTE zoomed apical four-chamber view in a patient with ischemic MR showing the color Doppler side lobe artifact on both sides of the vena contracta *(yellow arrows)*. **(C)** Two-dimensional TTE zoomed apical two-chamber view in the same patient demonstrates linear color Doppler side lobe artifact at the level of vena contracta like **(B)** *(yellow arrows)*. The side lobe artifact is formed as an "arclike" artifact at a constant distance from the transducer and makes it difficult to accurately measure the MR vena contracta.

6. ARTIFACTS IN 3D ECHOCARDIOGRAPHY

Currently, both 3D TTE and 3D TEE are indispensable tools for precisely defining aspects of a vast range of cardiac diseases, providing accurate images of normal and pathological morphology.[47-49] Both TTE and TEE may create the same types of artifacts encountered in 2D echocardiographic imaging.[49,50] Some artifacts, when displayed in 3D format, may appear more "realistic," while others are unique to 3D image acquisition. Awareness of these artifacts may avoid misinterpretation of 3D images.[51-54]

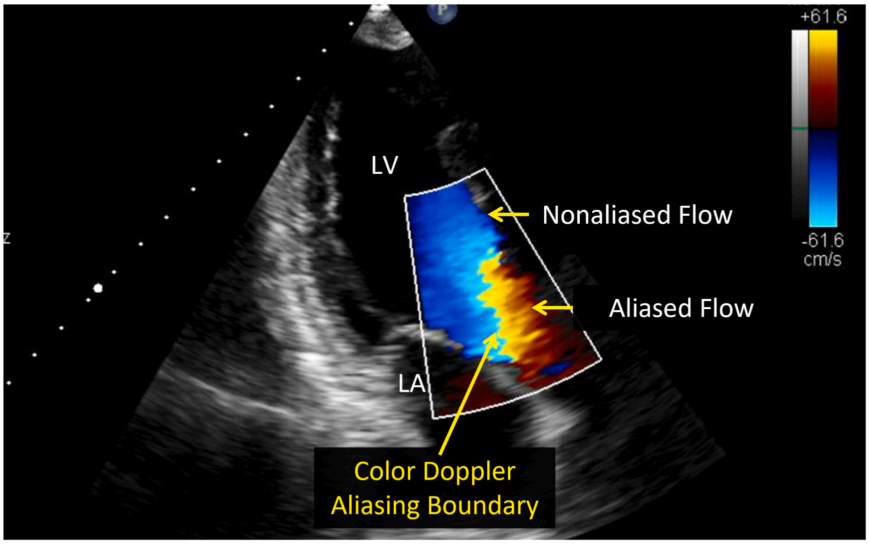

Figure 31 Color Doppler aliasing. Color Doppler study in TTE apical long-axis view demonstrates color Doppler aliasing in the LVOT when the velocity exceeds the Nyquist limit (in this case, 61.6 cm/s). *LA*, left atrium; *LV*, left ventricle; *LVOT*, left ventricular outflow tract.

6.1. Stitching (Reconstruction) Artifact

Appearance in image. Strong demarcations between subvolumes lead to a "broken" image. Figure 33A demonstrates stitch artifacts in a multibeat full volume en face view of mitral prostheses.[54,55]

Mechanism. Wide-angle volume multibeat acquisition captures a large volume by acquiring electrocardiogram-gated narrow sectors through 2 to 6 sequential beats. These sectors are electronically "stitched" together. This acquisition modality has 3 main advantages:

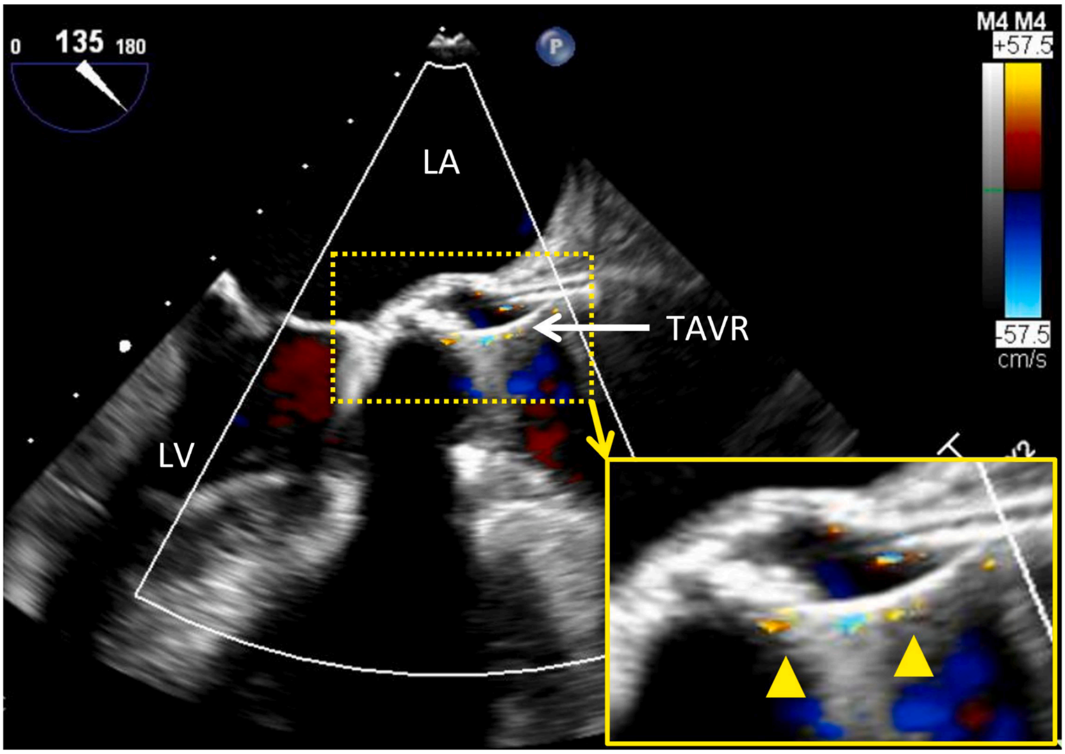

Figure 32 Color Doppler twinkling. Two-dimensional TEE midesophageal long-axis view of the aortic valve in a patient after transcatheter aortic valve replacement. Color Doppler imaging demonstrates twinkling artifacts (*yellow triangles* in the *inset*). *LA*, left atrium; *LV*, left ventricle; *TAVR*, Transcatheter aortic valve replacement.

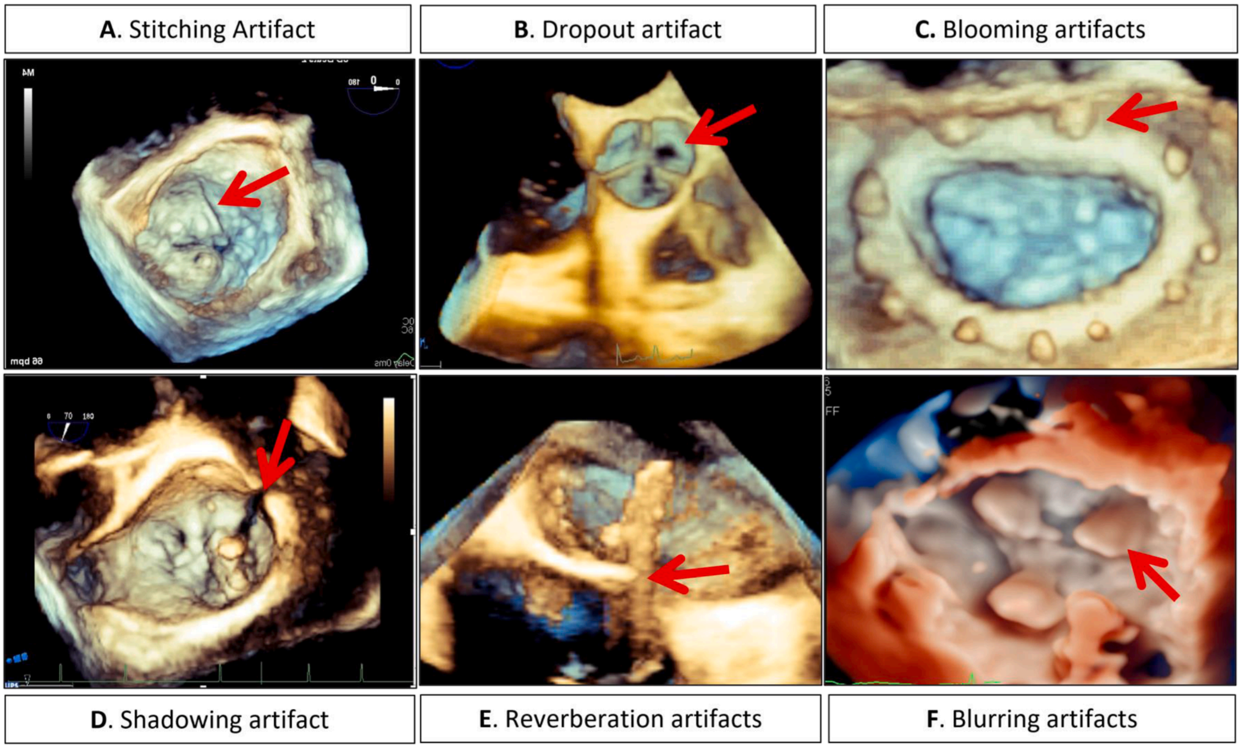

Figure 33 Three-dimensional artifacts. Common 3D echocardiography artifacts. **(A)** Stitching artifact of a native mitral valve. **(B)** Dropout artifact of a native aortic valve. **(C)** Blooming artifact of a prosthetic annuloplasty ring. **(D)** Shadowing artifact in the left atrium by a mitral clip. **(E)** Reverberation artifact in the left atrium by a catheter. **(F)** Blurring artifact of mitral bioprosthetic struts.

(1) a large pyramidal data set due to the summation of sectors, (2) a high-volume acquisition rate (i.e., number of volumes per second up to 100 Hz) due to the narrow sector acquired for each beat, and (3) high spatial resolution due to an increased line density for each sector. Because wide-angle volume is unavailable until the last sector is acquired, the final image is not in real time and cannot be used, for instance, during percutaneous intervention. The position of subvolumes may vary between sequential beats, resulting in incorrect juxtaposition at the interface of the sectors. As these out-of-phase sectors are merged, stitching artifacts may be created. This may be due to movement of the heart with respiration, patient or transducer movement during image acquisition, or variable cardiac cycle lengths (e.g., with marked sinus arrhythmia, atrial fibrillation, or premature ventricular complexes). Multibeat acquisition can also be used in conjunction with zoomed-mode image acquisition, and it may also exhibit stitch artifacts. While these stitch artifacts may be distracting and image distorting, they may also be used creatively to a beneficial effect, as described in the section below.[55-57]

Key Points

- In the 3D stitched artifact, the strong demarcations between subvolumes distort anatomic details and may interfere with correct diagnosis.
- In 3D imaging, stitch artifacts can occur because of a patient and/or operator-related motion.

Recommendations

- Ask the patient to hold their respirations during image acquisition.
- Limit the number of cardiac cycles used for acquisition to the minimum necessary for clinical accuracy; fewer beats mean less opportunity for misalignment and artifact formation.
- Use single-beat or 2-beat acquisition.
- Single-beat acquisition eliminates stitching artifacts entirely, making it especially useful for patients with arrhythmias or those unable to hold their breath.
- Two-beat acquisition also significantly reduces artifacts compared to traditional 4-beat methods, as it requires less breath hold and is less susceptible to rhythm irregularities.
- Optimize patient and probe stability.
- Eliminate arrhythmias, when possible, as irregular rhythms disrupt the synchronization of subvolumes and increase artifact risk.

6.2. Three-Dimensional Dropout Artifact

Appearance in image. Dropout artifacts typically appear as a lack of tissue on 3D images. One clue in distinguishing artifactual dropout from true anatomic defects and those of artifacts is that the borders of the artifactual holes are rather indistinct, while the borders of actual defects are more defined. Interestingly, the dropout artifacts of aortic leaflets do not occur in systole since the body of the leaflet is perpendicular to the ultrasound beam and generates strong echoes. Unlike dropouts, true holes demonstrate expected physiologic flow through them on color Doppler imaging (Figure 33B). The most common dropout artifacts occur in the foramen ovale of the interatrial septum, simulating atrial septal defect, and in the aortic and tricuspid leaflets, simulating leaflet perforations.[55-57]

Even in the most favorable conditions, the acquisition of aortic valve images in diastole may constantly present as dropout artifacts in the leaflet bodies. Similar to artifacts occurring in the foramen ovale, these artifacts are due to the nearly coaxial orientation of the leaflet body in diastole to the direction of the ultrasound beam. Only weak scattered echoes are reflected from these portions of the valve and thus scarcely return to the transducer.[55]

Mechanism. Dropout artifacts typically happen due to poor echo signal strength, particularly when the structure is not perpendicular to the ultrasound beam, produces less specular reflecting echoes, and appears as a dropout artifact.

Key Points

- The 3D dropout artifact may lead to misdiagnosis of a defect in the interatrial septum or create false holes in tissue such as the aortic valve.
- Three-dimensional dropout artifacts should be suspected when the defect has ill-defined borders, lacks physiologic flow on color Doppler, and corresponds to regions where the structure is nearly coaxial to the ultrasound beam.

Recommendations

In the 3D dropout artifact,
- Adjust the gain to be slightly overgained.
- Optimize compression.
- Image from a window where the structure is as perpendicular to the ultrasound beam as possible.
- Sometimes these artifacts cannot be eliminated, and color Doppler imaging may distinguish between true holes and dropout artifacts.

6.3. Three-Dimensional Blurring and Blooming Artifact

Appearance in image. In the assembly process, thin and elongated structures may appear with indistinct edges and increased size in those perspectives that use lateral rather than axial resolution. Calcifications and metallic structures (e.g., prostheses or guidewires) produce fringes that surpass the borders of the structure. This phenomenon is called blooming.[55-57] A blooming artifact of a mitral annuloplasty ring is shown in Figure 33C. Blurring artifacts of the bioprosthetic strut are shown in Figure 33F.

Mechanism. In 3D imaging, thin structures may appear thicker than they are. The axial, lateral, and elevational resolutions of the 3D volumetric data are nonuniform (i.e., axial resolution, ~1 mm; lateral resolution, ~2 mm; and elevational resolution, ~3 mm). These differences in spatial resolution create anisotropic voxels (i.e., voxels that have different dimensions in each of the 3 orthogonal axes).

6.4. Shadowing and Reverberation Artifact

Appearance in image. Shadowing artifacts cause dropouts that resemble a lack of tissue distal to a catheter/device. It can be recognized by its position, as well as its similar shape, size, and motion to the catheter. Three-dimensional shadowing by a mitral clip and reverberation artifacts by a catheter are shown in Figure 33D and E.

Mechanism. Shadowing and reverberation artifacts in 3D TTE and TEE have the same mechanism as 2D artifacts.[55]

Key Points

- In the 3D blooming and 3D blurring artifacts, the cardiac or metallic structures appear thicker than actual anatomy.
- Three-dimensional shadowing artifacts obscure structures distal to the shadow-producing structure.

Recommendations

- The 3D blurring artifact can be avoided by acquiring the 3D image from a different view that emphasizes axial resolution.
- Recognize the blooming artifact.
- Shadowing artifact can be avoided by using different ultrasound imaging angles.

7. ARTIFACTS WITH UEA

Ultrasound-enhancing agents are small, encapsulated gas-filled microbubbles that pass through the pulmonary capillaries and can be visualized in the heart during echocardiographic imaging after intravenous administration.[58] They expand and compress when they interact with ultrasound waves. This causes nonlinear oscillation of the microbubbles, resulting in a strong backscattered signal, allowing the imager to better delineate the blood-tissue interface within the LV. It has become standard practice to use UEAs when 2 or more segments of the endocardium are not well visualized in any of the 3 apical windows.[59]

When imaging the LV, the image should have homogeneous UEA opacification from the apex to the base (Figure 34A, Video 20). The mechanical index (MI) is a unitless measurement of negative acoustic pressure within the ultrasound field and is calculated at the depth where energy concentration is highest. Typically, a low MI is used during the administration of UEAs, since a high-MI imaging can destroy microbubbles. To improve technique and diagnostic accuracy, it is important to recognize imaging artifacts that may occur when using UEAs.[59,60]

7.1. Attenuation Artifact

Appearance in image. This artifact is typically characterized as dark shadowing in the mid-to-far field of the ultrasound sector. Attenuation in the LV may occur while using UEA to examine for apical thrombus (Figure 34B, Video 21).

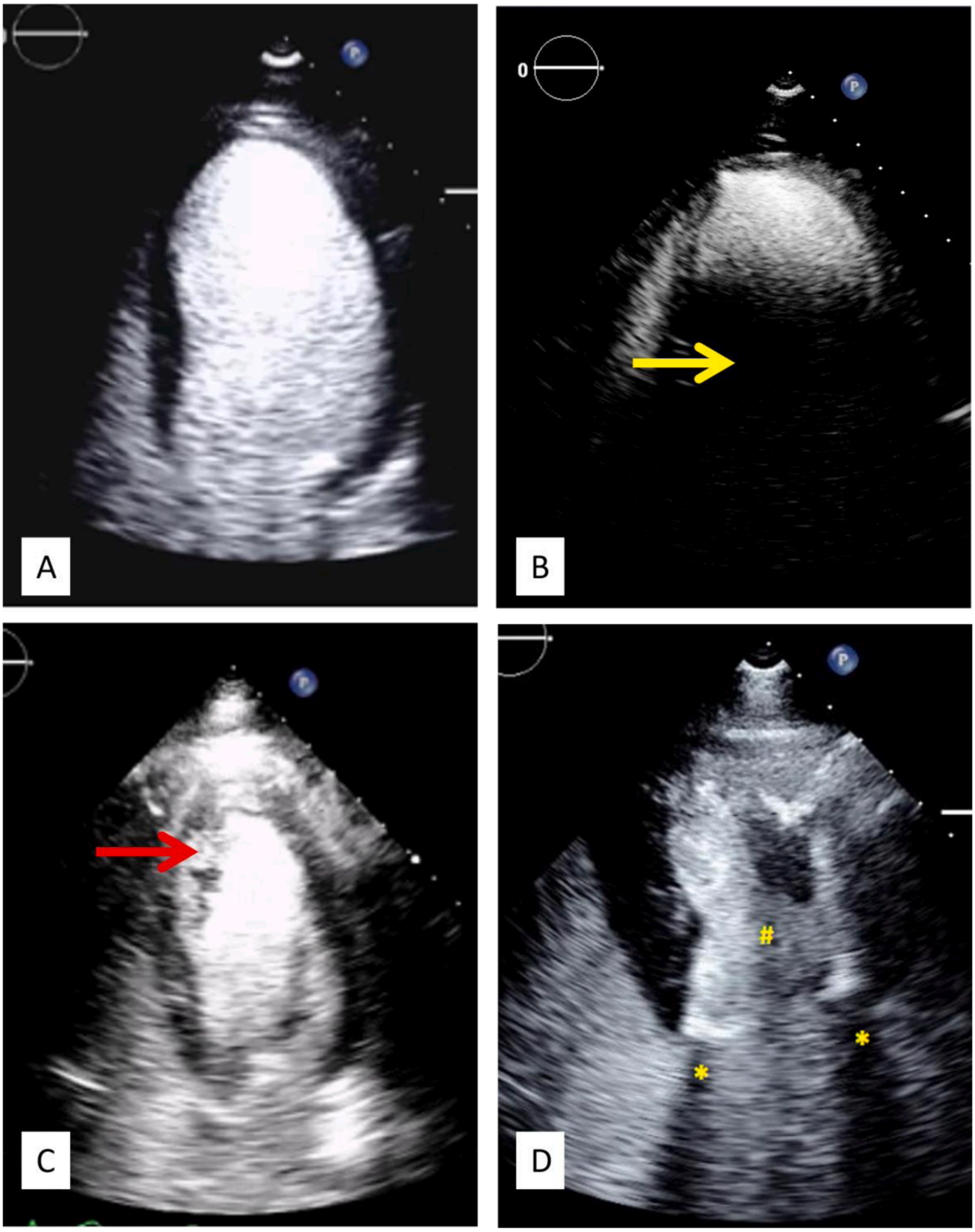

Figure 34 UEA artifacts on 2D imaging. Two-dimensional TTE apical four-chamber views of the LV. **(A)** Normal appearance of UEA: note the homogeneous opacification of the LV from apex to base. **(B)** UEA attenuation artifact *(yellow arrow)* with a high concentration of UEA microbubbles in the near field due to a fast bolus injection. **(C)** Swirling artifact *(red arrow)* due to low cardiac output and elevated mechanical index. **(D)** Multiple imaging artifacts. The hypoechoic region or shadowing artifacts *(yellow asterisks)* are noted beneath the mitral annular calcification. A prominent papillary muscle obstructs the LV volume and causes an edge shadowing artifact *(yellow hash mark)*.

Mechanism. Attenuation during contrast echocardiography occurs when there is a high concentration of UEA microbubbles in the near field, resulting in the ultrasound waves being reflected, scattered, absorbed, and unable to penetrate to the far field. Attenuation often occurs when the UEA travels to the heart quickly. For example,

- A rapid injection of UEA or a postinjection rapid flush.
- A high cardiac output state and/or tachycardia.
- Injection through a central line, which has a higher chance of attenuation versus antecubital intravenous line with long extension tubing.

Because UEAs are diluted by blood, attenuation diminishes over time as the microbubble concentration decreases in the near field.[61-63] The imager should delay image acquisition until attenuation disappears.[64]

During treadmill stress echocardiography, which creates a high-flow state, the UEA should ideally be administered 30 to 60 s before the patient ceases the stress test, allowing the concentration of UEA to be reduced by the time poststress imaging is performed.

Key Points

- In the attenuation artifacts, the structures in the mid-to-far field are not well visualized.
- However, the cardiac apex is nicely opacified during attenuation, allowing images to be acquired that address clinical questions about apical pathology (e.g., apical thrombus, hypertrophy, aneurysm).

Recommendations

- Attenuation artifacts during contrast echocardiography can be avoided by techniques that decrease the concentration of UEA microbubbles, such as,
- Delivering the UEAs bolus slowly.
  - ○ Small bolus injections.
  - ○ Injections via diluted continuous infusion.
- When injecting through a central line, giving an even slower bolus than normal and/or a lesser dose may be helpful in decreasing attenuation.
- If attenuation is consistent during postexercise images, a high-MI “flash” feature can be used to destroy the microbubbles in order to visualize the basal portion of the LV.
- Delay the image acquisition until attenuation disappears.

7.2. Ultrasound-Enhancing Agents Swirling

Appearance in image. Swirling with UEA presents as a heterogeneous, twisting, or circular movement of the blood pool, characterized by varying degrees of echogenicity. Swirling may occur after UEA administration in a patient with left ventricular apical or global hypokinesis (Figure 34C, Video 22).

Mechanism. Swirling results when there is UEA microbubble destruction or when there is an insufficient amount of UEA within the blood. Causes of swirling include a high MI, slow rate of UEA administration, inadequate dose, decreased left ventricular systolic function, high-frequency probe, poor focal zone placement, high scan line density, and high frame rate. When imaging with a high MI (0.7 or higher), most of the UEA microbubbles are destroyed and swirling will occur.[62-64] Swirling can often be a result of imaging with an excessive MI, and thus, optimal imaging is at a low MI of <0.3 or very low MI of <0.2 utilizing imaging pulse sequence schemes that detect fundamental and/or harmonic frequencies.

Optimal scanning during UEA administration requires agent-specific imaging protocols that modify MI, gain, focus, frame rate, dynamic range, and other measures.[60] Ultrasound-enhancing agent microbubble response when imaging at a mid-range MI (up to 0.5) results in both nonlinear oscillations and nonlinear disruptions of the microbubbles, and thus, there will be some microbubbles that remain intact while others are destroyed, resulting in swirling.[63] The MI threshold may vary depending on the patient’s size and imaging window depth. With that in mind, increasing the MI may cause discontinuities or cracks in the microbubble shell, as the oscillations become more exaggerated. If the MI is set too low (<0.1), very low linear oscillation of the microbubbles occurs, resulting in poor returning signals and a dark, ill-defined image.

The frequency should be as close as possible to the resonance frequency of the UEA being used (2.0-5.0 MHz). When using UEAs during transesophageal imaging, the lowest frequency available should be used to allow a longer duration of microbubble oscillation.[64]

Key Points

- Ultrasound-enhancing agents–induced swirling artifacts can occur in the setting of reduced left ventricular systolic function or the presence of an apical wall motion abnormality, even with optimal UEA equipment settings.
- It is important to rule out left ventricular thrombus, which appears as a black “filling defect” with UEA imaging.

Recommendations

To reduce swirling,

- Increase the dose.
- Administer a bolus more quickly.
- Keep the imaging focus at the mitral annular level to allow homogeneous opacification of the LV. It helps reduce microbubble destruction since the highest intensity of the ultrasound beam is at the focal zone.
- Adjusting the frequency may help in mitigating the swirling artifact.

7.3. Ultrasound-Enhancing Agents Doppler Blooming

Appearance in image. When using UEAs, color Doppler signals appear exaggerated and extend beyond true anatomic boundaries. High-intensity transit signals may appear on the spectral Doppler signal when a UEA is present. It may cause overestimation of peak velocities for TR or aortic stenosis. When administering a UEA, an exaggerated color Doppler signal causes an erroneous qualitative assessment of valvular regurgitation or stenosis (Figure 35A and B, Video 23).

Mechanism. Ultrasound-enhancing agent Doppler blooming is caused by microbubble destruction along the Doppler sample line, resulting in a broadband pulse that contains many frequencies.[61-63] The color and spectral Doppler blooming artifacts result from a returning Doppler signal that is too strong (high intensity). The exaggerated color Doppler signal can be helpful in properly aligning the spectral Doppler cursor within a regurgitant jet, most commonly the tricuspid regurgitant jet, whose peak velocity is measured for assessment of right ventricular systolic pressure (Figure 35C and D).

7.4. Ultrasound-Enhancing Agents Shadowing Artifact

Appearance in image. With UEA imaging, the artifact presents as a black (anechoic) shadow distal to the strongly reflecting structure such

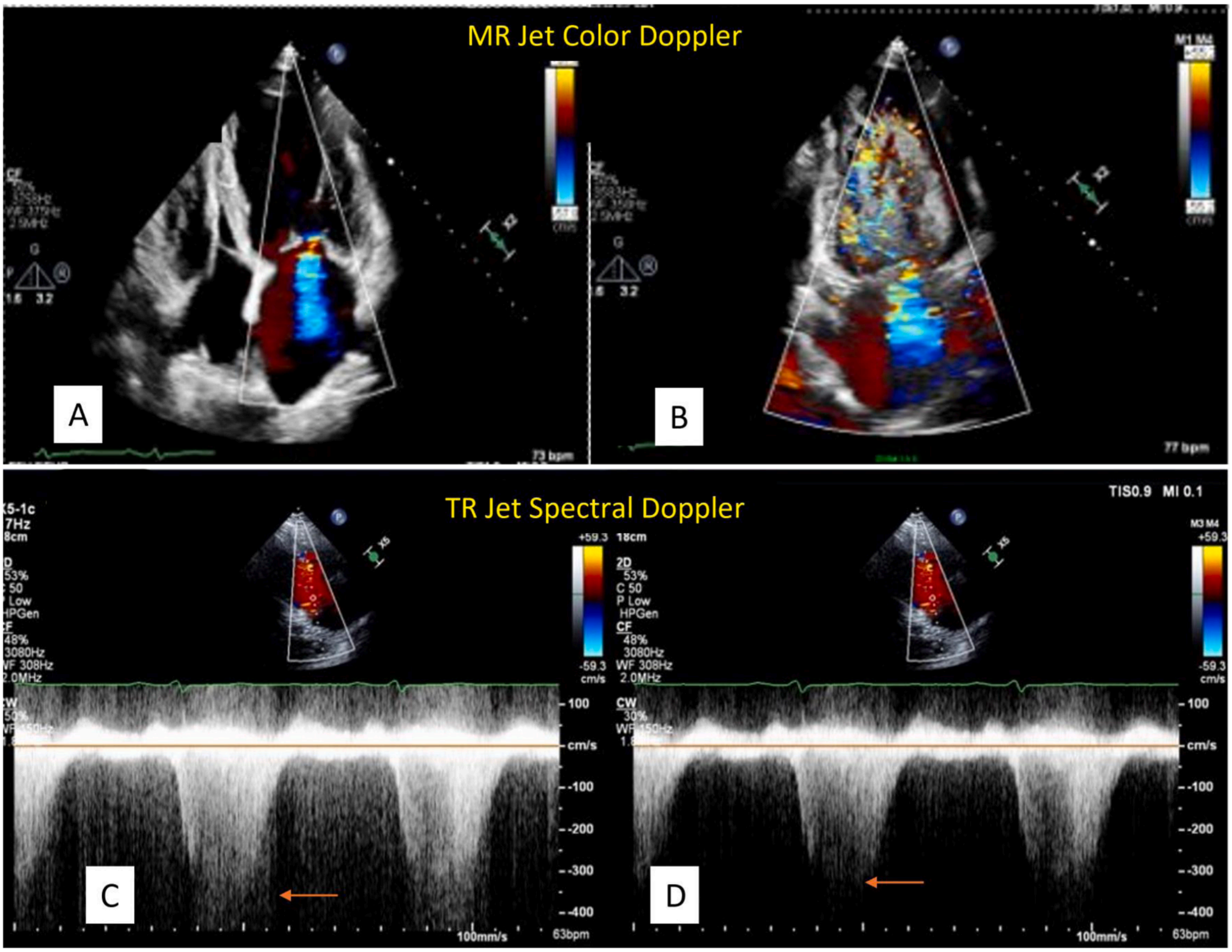

Figure 35 UEA artifacts on Doppler imaging. **(A)** Color Doppler study of the mitral valve before injecting a UEA reveals mild regurgitation. **(B)** Acquisition from the same window after injecting the UEA; note the blooming artifact revealed as color Doppler signals in the left ventricle and exaggeration of the MR jet. **(C)** CW spectral Doppler signal of TR recorded with UEA and high Doppler gain. Peak TR velocity is spuriously increased, leading to overestimation of right ventricular systolic pressure. **(D)** Properly recorded TR signal with appropriate Doppler gain after reduced contrast effect as the microbubble concentration decreases over time.

as beneath the mitral annular calcification. A prominent papillary muscle is obstructing the left ventricular cavity as well as causing an edge shadowing artifact (Figure 34D).[61-64]

Mechanism. As described earlier in this document, acoustic shadowing occurs when the transmitted ultrasound beam is partly or completely reflected or absorbed by the tissue. Acoustic shadowing can be seen from a highly reflective structure, such as a calcified mitral annulus, a calcified mass, or a rib.

Key Points

- Ultrasound-enhancing agents Doppler blooming can be useful for enhancing spectral Doppler signals.
- If the spectral Doppler “noise” is measured, it could lead to velocity overestimation such as overestimation of the severity of pulmonary hypertension or aortic stenosis.

Recommendations

- Wait until most of the UEAs have dissipated before assessing with spectral Doppler to minimize the “noise.”
- Lower the spectral Doppler gain to a level that reduces the blooming.
- Avoid qualitative grading of the severity of a valvular regurgitant using color with Doppler blooming as it can lead to overestimation.

8. ARTIFACTS DUE TO EQUIPMENT AND DEVICES

Many pieces of equipment in the exam room may cause interference with the ultrasound signal.

8.1. Originating from Equipment External to the Heart

Appearance in image. An electrical artifact is easily recognized as a geometric shape that does not stay within the borders of the cardiac structures and appears in all windows while the electrical equipment is still on. External electrical signals can create a band within the 2D and color Doppler imaging sectors (Figure 36A). External cautery, as used in the operating room, causes a fan-shaped artifact that is seen throughout the ultrasound image without respecting chamber boundaries (Figure 36B, Video 24).

Mechanism. Electrical equipment such as electrocautery devices may be used during echocardiograms. External electrical signals may interfere with the reflected ultrasound signal and cause artifacts.[65]

8.2. Ultrasound Probe Malfunction

Appearance in image. Probe malfunction artifacts generally appear as single or multiple curved, bright or dark lines, visible in all images and views. Figure 37A demonstrates a spectral Doppler study of the tricuspid valve flow being interfered with by the vertical dark strips due to TEE probe malfunction.

Mechanism. The malfunction may originate from the ultrasound system or the transducer itself.

8.3. Cross Talk Phenomena

Appearance in image. Irregular and repetitive echoes occur throughout the image. Regardless of the probe used, all images in all views will demonstrate this artifact (Figure 37B, Video 25). Cross talk artifacts may be caused by the simultaneous use of both TEE and intracardiac echocardiography during transcatheter procedures. Other causes include simultaneous use of vascular ultrasound for arterial or venous access during TTE or TEE in patients with pulmonary embolism receiving ultrasound-enhanced catheter-directed thrombolysis.

Mechanism. The simultaneous use of 2 ultrasound systems can lead to a cross talk artifact when ultrasound energy generated by one system is picked up by another.

Key Points

- External electrical equipment can contaminate the ultrasound signal. These artifacts are nonanatomical and do not relate to the patient or the ultrasound system itself but originate from outside electrical sources such as,
- A broken ultrasound probe or its communication with the ultrasound system.
- Improper electrical shielding of surrounding equipment.
- Simultaneous use of surgical cautery equipment.
- Electrical artifacts obscuring the visualization of true anatomic structures.
- Transducer malfunction limiting echocardiographic assessment of the region of interest.
- Cross talk artifacts obscuring true anatomic structures. They should be expected during the simultaneous use of 2 ultrasound systems and not mistaken for system malfunction.

Recommendations

- When a probe malfunction is suspected, a different probe should be used. If the artifact is no longer visible, this documents the source of the error.
- The faulty probe should not be used for clinical scanning until the necessary repairs have been made.
- Avoid the simultaneous use of cardiac ultrasound and surgical cautery equipment. Some ultrasound manufacturers have built-in mitigation software that eliminates the cautery artifact.
- For cross talk artifacts, simultaneous use of 2 ultrasound systems should be avoided.
- Properly shield the electrical equipment surrounding the ultrasound machine or turn off the source of unshielded electrical energy.

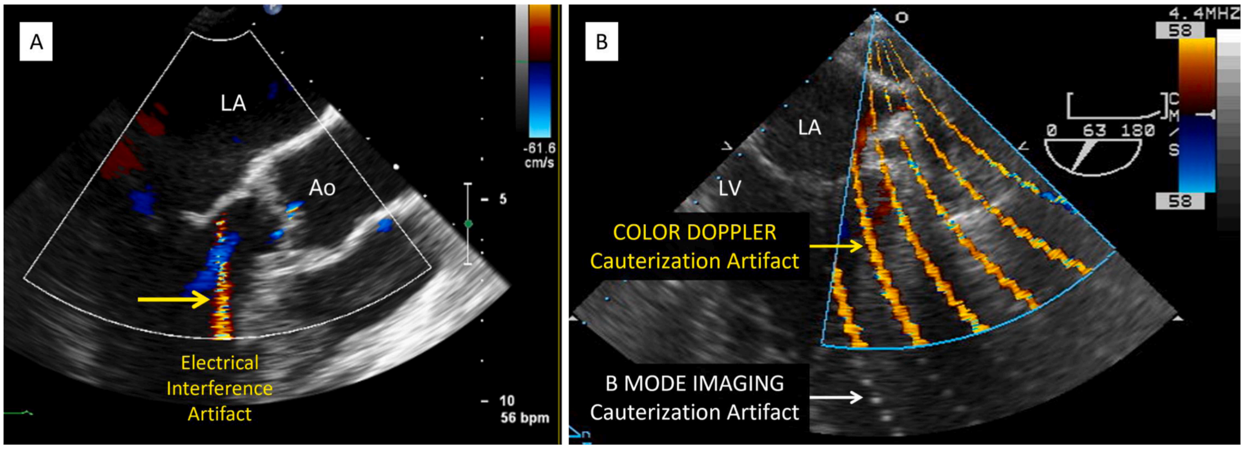

Figure 36 Electrical and cauterization interference. **(A)** Color Doppler study during 2D TEE demonstrates the artifact due to electrical interference *(yellow arrow)* from unshielded electrical appliances or a broken probe. **(B)** Cauterization artifact on B-mode *(white arrow)* and color Doppler *(yellow arrow)* imaging. *Ao*, Aortic valve; *LA*, left atrium; *LV*, left ventricle.

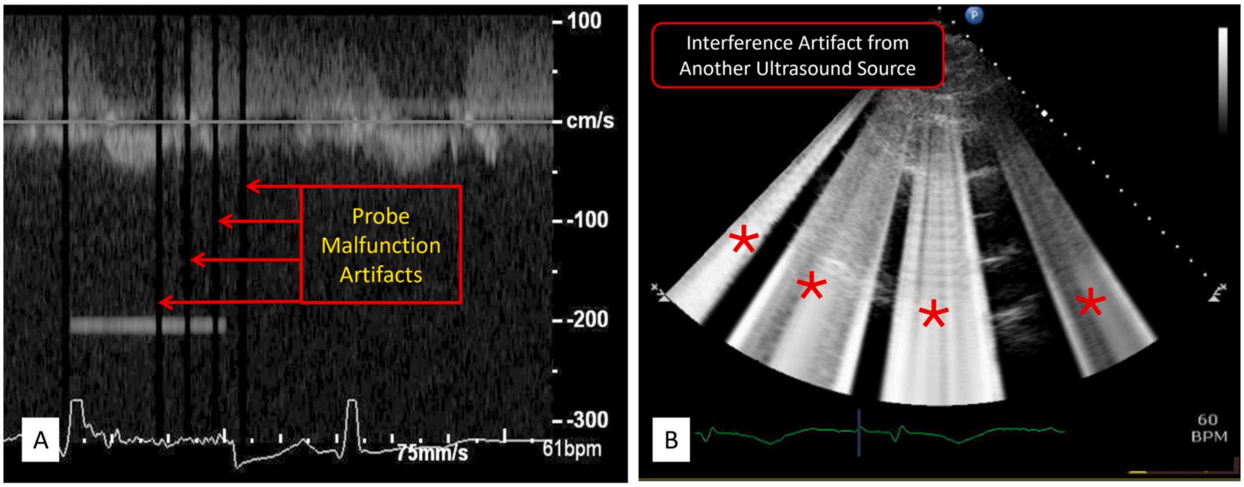

Figure 37 Probe malfunction and crosstalk interference. **(A)** Spectral Doppler interrogation of the tricuspid valve during TEE demonstrates intermittent dark vertical lines through the tracing, suggesting probe malfunction *(red arrows)*. **(B)** Crosstalk interference artifact happens when ultrasound waves from two different sources interact to create an artifact. This TTE parasternal long-axis view demonstrates fanlike artifacts *(red asterisks)* caused by interaction with a second ultrasound source used for ultrasound-assisted thrombolysis of pulmonary thromboembolism.

8.4. Artifacts Originating from Devices Internal to the Heart

Ventricular Assist Device–Related Artifacts Appearance in image. Multiple equally spaced wave-like pattern artifacts can be seen during 2D and Doppler interrogation. Ventricular assist devices (VADs) obscure 2D imaging of any far field structures.

Figure 38A demonstrates wave-like patterns on spectral Doppler imaging in a patient with a left VAD (LVAD), and Figure 38B shows a characteristic LVAD "waterfall" artifact generated by reverberation from the device in color Doppler (Video 26).

Mechanism. Ventricular assist devices create both 2D shadowing and Doppler interference artifacts due to the proximity of the electromagnetic motor system to the ultrasound machine.

Cardiac Implant–Related Artifacts Appearance in image. These artifacts can be recognized by knowing that unexpected linear targets are secondary to the implant. In spite of artifacts, misdiagnoses must be avoided, and efforts must be made to image all important cardiac structures. Cardiac implants, including valvular prostheses (Video 4), total artificial hearts, LAA closure devices, septal occluders, edge-to-edge closure devices, and wires (Figure 39A), may create a variety of artifacts.

Mechanism. Devices implanted into the heart may create shadowing artifacts, reverberation, and side lobe artifacts, with identical mechanisms as described in relevant sections above.

Pacer wires and catheter-related artifacts—Wires and catheters can create reverberation, shadowing, side lobes, and mirror image artifacts

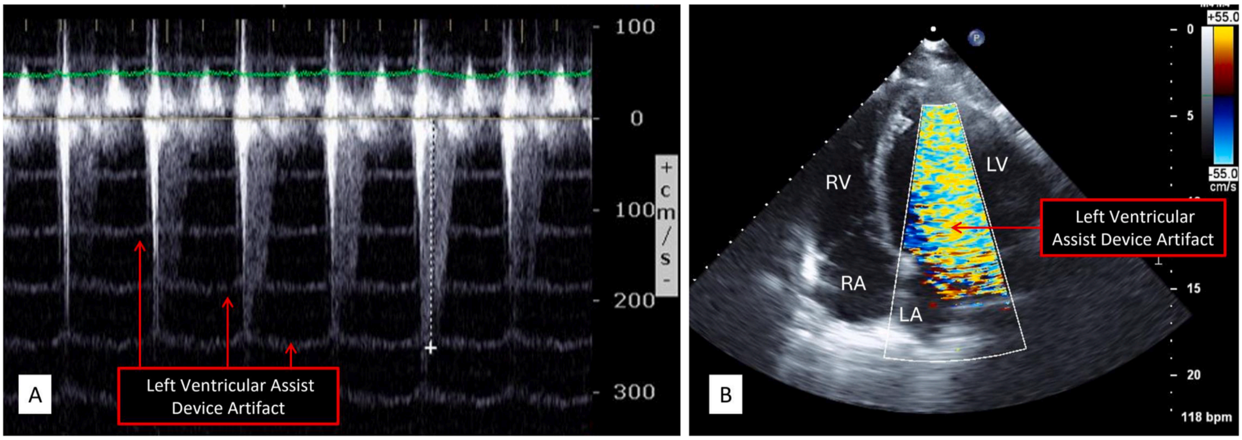

Figure 38 Artifacts related to circulatory assist devices. **(A)** Spectral Doppler study of tricuspid valve inflow in a patient with a LVAD showing regularly spaced wavy horizontal artifacts *(red arrows)* superimposed on the CWD tracing of TR. **(B)** LVAD-related color Doppler artifact. *LA*, left atrium; *LV*, left ventricle; *RA*, Right atrium; *RV*, right ventricle.

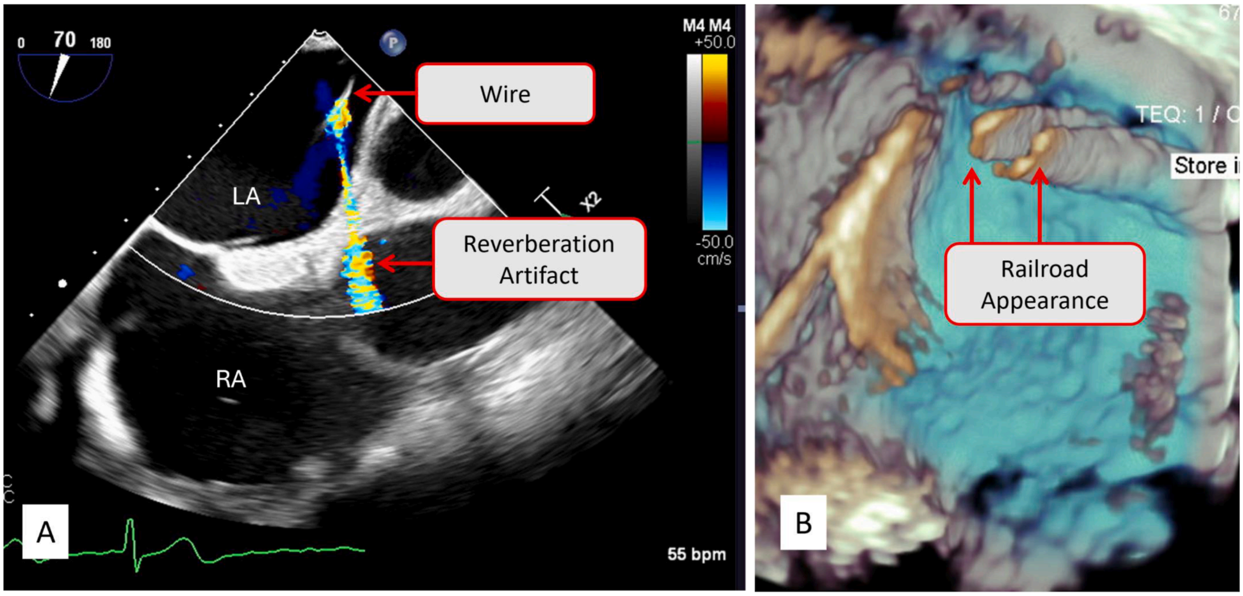

Figure 39 Artifacts related to devices in the heart. **(A)** Color Doppler reverberation artifact due to a wire in the LA during LAA closure procedure. **(B)** Three-dimensional TEE image demonstrating a railroad-like appearance of a guide catheter in the LA. *RA*, Right atrium.

as described earlier in this document. These artifacts can be seen with catheters, pacing leads, and extracardiac devices such as catheters in the aorta (intra-aortic balloon pump) and inferior vena cava (extracorporeal membrane oxygenation).

Appearance in image. Large-bore catheters, through which several delivery systems can be advanced, produce a typical railroad-like image. Because of the wide lumen, the pyramid-shaped ultrasound beam intersects 2 surfaces perpendicularly (superior and inferior) and 2 surfaces tangentially (medial and lateral). While the echoes reflecting from perpendicular surfaces are strong and specular, echoes reflecting from the tangential surfaces are scattered and do not contribute to the tridimensional reconstruction of the image. Consequently, the catheter appears to be formed by 2 parallel narrow strings (Figure 39B).[59]

Catheter shadowing causes a dropout artifact that resembles a lack of tissue. It can be recognized because it is just beyond the catheter/device, has the same shape and size, and follows the catheter's motion. Shadowing is inevitable; however, it may be covered by the same catheter, causing the artifact.

Mechanism. Wires and catheters present in the heart are highly reflective structures that create both axial and lateral artifacts. The guidewires and sheaths may produce variable blooming artifacts depending on the direction in which the ultrasound beam intercepts the device.

Figure-of-8 Phenomenon Appearance in image. Figure-of-8 is a particular imaging phenomenon on 2D and 3D echocardiography, seen with a variety of Amplatzer devices (Abbott Laboratories), including atrial septal defect, patent foramen ovale, and LAA disk and lobe closure devices. The figure-of-8 could be frequently appreciated in both 2D and 3D TTE and TEE imaging after insertion of an Amplatzer Amulet device to close the LAA (Figure 40).

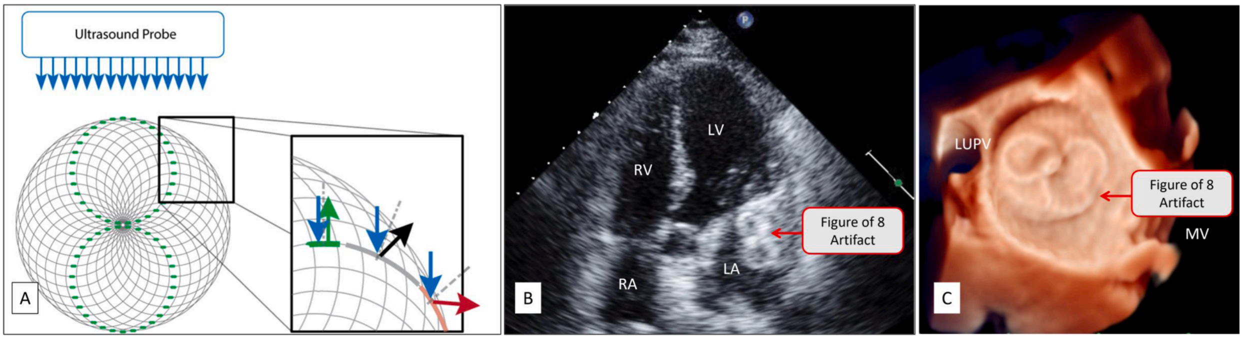

Figure 40 Figure-of-eight artifact. **(A)** Ultrasound waves hitting a meshed septal closure device are deflected in many directions because of the heterogeneity of mesh fiber orientations. When the ultrasound wave interacts with a meshed device at a perpendicular angle, the ultrasound energy will be reflected toward the transducer *(green arrow)*. Other mesh sections will refract the ultrasound only partly *(black arrow)*, or not at all *(red arrow)*. The figure of eight represents the section of the mesh with the highest ultrasound wave reflectivity *(green areas)*. Reproduced from Bertrand *et al*.[66] **(B)** Figure of eight created by an LAA disk-and-lobe closure device seen in TTE apical four-chamber view. **(C)** Figure of eight seen in TEE en face 3D zoom view of an LAA disk-and-lobe closure device. *LUPV*, Left upper pulmonary vein; *MV*, mitral valve; *RA*, right atrium; *RV*, right ventricle.

Mechanism. Amplatzer devices are constructed of self-expanding nitinol wires woven into the disk.[66] The ultrasound waves are reflected from the Amplatzer device in multiple directions due to the heterogeneity of mesh fiber orientations.

In those mesh sections with tangential vectors perpendicular to the incoming ultrasound wave, the ultrasound energy will be reflected toward the transducer, while other mesh sections will refract the ultrasound waves sideward or completely deflect the ultrasound waves away from the probe. The resulting image will mainly comprise those regions with the highest ultrasound wave reflectivity, which leads to the figure-of-8 display.

Key Points

- Artifacts originating from devices internal to the heart are a common finding and cannot be eliminated.
- The interpreter must recognize the VAD-related artifacts
- The interpreter must assess hemodynamics by using those 2D and Doppler tracings that are not obscured by artifactual signals.

Recommendations

- Recognize the artifactual images from cardiac implants.
- Decrease the gain, change the imaging window, and adjust the depth to minimize or mitigate the artifact.
- Artifacts created by indwelling pacers and catheters can be identified by changing the imaging window and image depth of field, which will either eliminate the artifact or change its location relative to cardiac structures and clearly identify it as an artifact.

9. ARTIFACTS WITH POTENTIALLY SERIOUS CONSEQUENCES

Ultrasound artifacts can have a devastating clinical impact when their misdiagnosis leads to unnecessary and high-risk cardiovascular intervention or when a potentially clinically important diagnosis is missed. The most common clinical scenarios of potentially dangerous artifact-related misdiagnoses and missed diagnoses are summarized in Table 2.

Artifacts mimicking aortic dissection are common. Figure 41 and Video 3 show examples of 2D artifacts falsely interpreted as aortic dissection flaps on 2D TEE imaging. Key features of true dissection flaps are their independent mobility (unless intramural hematoma), their attachment to other structures, their respect for physical boundaries (flaps cannot pass through the aortic wall), and their acting as flow dividers within the aorta. Clues to the presence of linear artifacts instead of a true dissection flap are the lack of well-demarcated borders and attachments (i.e., the potential flap is appearing to pass through walls), the identical (or mirrored) motion relative to surrounding structures with a lack of independent motion, the fact that color Doppler flow is unaffected by the artifact, and the inability to reproduce the artifact in alternative imaging windows.

Intracardiac masses can be missed on echocardiography when located in a portion of the heart that is obscured by the presence of ultrasound artifacts. An example of acoustic shadowing masking true intracardiac masses may be seen in Figure 42.

The near field clutter (NFC) artifact is a common ultrasound artifact and can be misleading in detecting the true apical LV thrombus (Figure 43). The NFC artifact was previously considered a transducer-originated artifact due to high-amplitude oscillations of the piezoelectric elements. Currently, the availability of the tissue harmonic imaging mode in ultrasound machines has improved image quality. Recently, other mechanisms, such as reverberation artifacts with or without accompanying refraction, have been proposed as the mechanism of NFC artifact.[67] Clutter is unaffected by ventricular wall motion and appears to pass through the wall. When uncertain, applying color Doppler and reducing the scale to demonstrate blood flow through the apex can be considered. In addition, switching to alternative imaging planes or the use of a UEA should be considered to confirm or refute the presence of an apical thrombus. Alternative imaging with computed tomography or CMR may also be needed.

The 2D dropout phenomenon is a common finding in the 2D echocardiogram. Considering the fact that optimal 2D image generation happens when the insonation beam is perpendicular to the structure, a false 2D dropout occurs when the angle of the insonation beam is parallel to the tissue and results in no or a small amount of reflected beam reaching the transducer. It may lead to a false appearance of absence of tissue or a defect in the ultrasound image.[6] The echo dropout phenomenon can lead to confusion between the true and pseudo defects in the interatrial or ventricular septum in the apical 4-chamber view.[68]

10. USEFUL ULTRASOUND ARTIFACTS

Some artifacts could be useful in identifying the pathology, interpreted as signs of the severity of the condition, or have prognostic importance in interpreting the result of the echocardiographic studies. They are summarized in Table 3.

For example, the aliasing artifact is intentionally exaggerated by shifting the color baseline in the direction of the jet flow to obtain a larger hemisphere of isovelocity to measure the effective orifice area. Figure 44 demonstrates shifting the color Doppler baseline to create a distinct aliased hemispheric boundary. Additionally, stich artifacts could be used in scallop detection in patients with mitral valve prolapse/flail and MR (Figure 45, Video 27) as well as in visualization of LAA anatomy.[69]

11. FUTURE DIRECTIONS AND CONCLUSION

Despite significant advancements in cardiac ultrasound technology, diagnosing and avoiding image artifacts still remains a challenge, as artifacts result from the physical properties of the ultrasound wave.

However, ongoing innovations in ultrasound imaging hardware and software intelligence can be promising to minimize the generation of artifacts. For example, artificial intelligence tools, through deep learning algorithms, can automatically recognize common artifacts and guide users on how to modify the imaging plane or adjust settings to avoid artifact generation.

With the evolving therapeutic interventions, it is expected that new intracardiac and extracardiac devices will generate artifacts with an unknown mechanism. Collaborating with engineers and medical physicists to develop models that understand artifact generation will

Table 2 Artifact-related misdiagnoses and missed diagnoses with potentially serious consequences

	Potential misdiagnoses/missed diagnoses	Artifacts misinterpreted as obscuring true pathology	How to interpret	How to enhance diagnosis
1	Aortic dissection	Reverberation, side lobe and comet tail artifacts mimicking or obscuring dissection flap	True dissection flap is an undulating linear mobile echo density. It respects physical boundaries and acts as a flow divider in the aorta. The artifactual densities have identical (or mirrored) motion relative to surrounding structures with a lack of independent motion, lack of well-demarcated borders and attachments.	• Adjust 2D gain. • Add color Doppler imaging. • Use alternative imaging plane. • Use UEAs. • Consider alternative tomography-based imaging modalities such as CT or CMR.
2	Mechanical prosthetic pseudo-MR or masked MR	Color Doppler mirroring, reverberation or acoustic shadowing of color Doppler	Color Doppler signals present or absent in the LA mimicking or obscuring MR.	• Use alternative imaging planes. • Use spectral Doppler to demonstrate absence or presence of true MR flow. • Use alternative imaging modalities (such as TEE).
3	Presence or absence of intracardiac mass or thrombus	Acoustic shadowing, refraction artifacts	Intracardiac masses may be mimicked or obscured by strong reflectors (calcifications, prosthetic material).	• Use alternative imaging planes. • Use alternative imaging modalities (TEE, CT, CMR).
4	Presence or absence of apical left ventricular mass or thrombus	NFC	Obscured structures in the near field of the ultrasound transducer. Mass in the LV apex surrounded by hypocontractile LV segments is likely a thrombus.	• Optimize image. • Use UEAs.
5	Misdiagnoses and missed diagnoses ASD/VSD	Parallel insonation of atrial or ventricular septum	2D dropout in atrial or ventricular septum may lead to pseudo-ASD or VSD interpretation if viewed in apical 4-chamber view.	• Image in multiple views, particularly the subcostal 4-chamber view with ultrasound beam perpendicular to the septum. • Identify true defect with color Doppler study and intravenous injection of agitated saline.

ASD, Atrial septal defect; *CT*, computed tomography; *VSD*, ventricular septal defect.

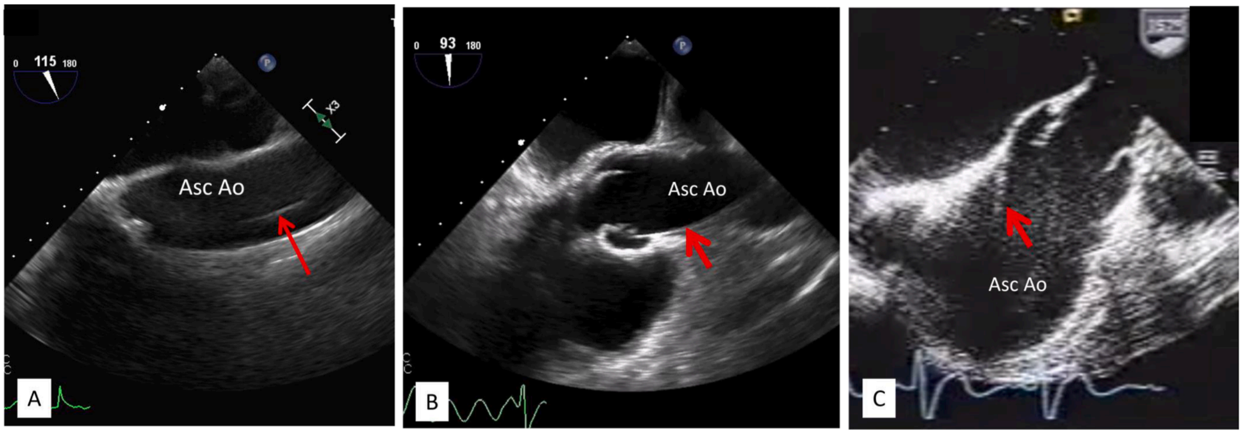

Figure 41 Artifacts in the ascending aorta (Asc Ao) that may be interpreted as life-threatening findings. Two-dimensional TEE long-axis view of the Asc Ao shows artifacts with different mechanisms, all mimicking a dissection flap *(red arrows)*. **(A)** Linear echo density in the Asc Ao *(red arrow)* representing a reverberation artifact originating from the adjacent pulmonary artery wall and mimicking an intimal flap. **(B)** Side lobe artifact caused by the highly reflective calcified sinotubular junction. **(C)** Transgastric artery view shows linear echo density due to comet tail artifact.

help identify how to avoid these artifacts. Undoubtedly, operator education in recognizing artifacts and implementing mitigation or avoidance strategies is of utmost importance. Simulation-based training modules can be helpful in training.

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REVIEWERS

This document was reviewed by members of the 2025–2026 ASE Guidelines and Standards Committee, ASE Board of Directors, and designated reviewer Dr. Andrew Pellett.

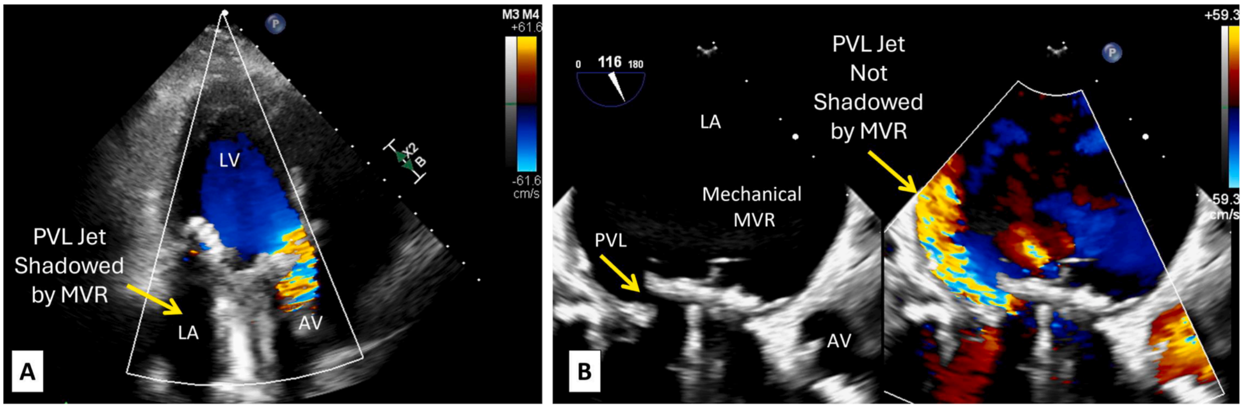

Figure 42 Acoustic shadowing artifact. Acoustic shadowing artifact in the LA caused by a mechanical mitral valve, potentially leading to missing a significant paravalvular leak. **(A)** Two-dimensional TTE, apical long-axis view of acoustic shadowing *(yellow arrow)* due to the mitral mechanical valve. **(B)** Two-dimensional TEE of the same patient with the application of color Doppler demonstrates a significant paravalvular leak *(yellow arrow)*, potentially missed on TTE due to acoustic shadowing of same patient. *AV*, Aortic valve; *MVR*, mitral valve replacement; *PVL*, paravalvular leak.

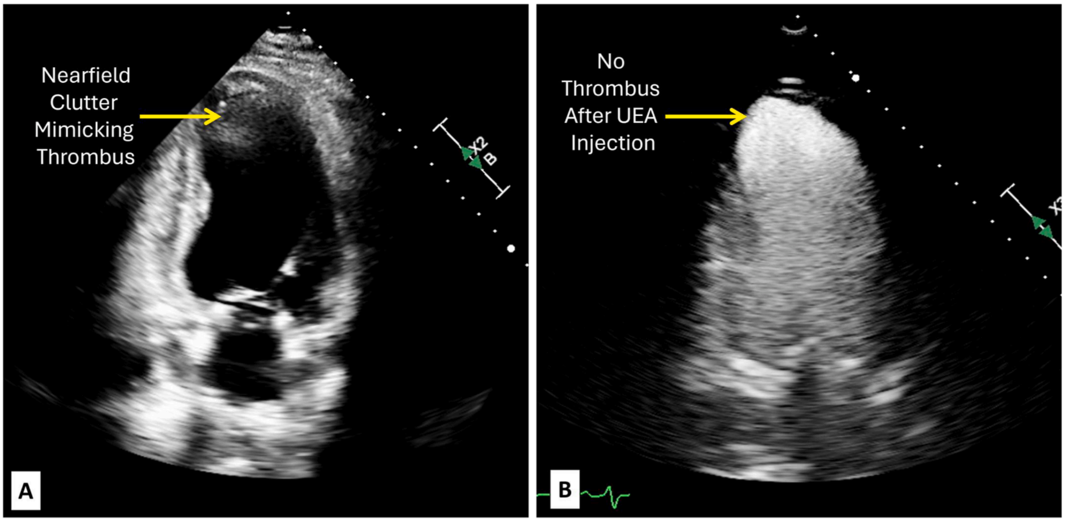

Figure 43 Near-field clutter mimicking an apical LV thrombus. Near-field clutter is potentially misinterpreted as a true apical LV thrombus. **(A)** Two-dimensional TTE apical two-chamber view showing near-field clutter that mimics a true apical thrombus *(yellow arrow)*. **(B)** Two-dimensional TTE apical two-chamber view after injecting UEA delineates no thrombus *(yellow arrow)* of same patient.

Table 3 Beneficial ultrasound artifacts or artifact-like phenomena

Type	Artifact	Tissue	Imaging appearance and clinical utility
Reverberation	A lines	Lung	• Repeated reverberation artifacts originating from the pleura and extending into the lung fields appear as repetitive, evenly spaced horizontal lines. • A lines could be seen in the normal lung or in some pathologic conditions such as pneumothorax and chronic obstructive pulmonary disease.
Ring-down	B lines	Lung	• B lines are ring-down artifacts and appear as a linear hyperechoic and dynamic artifact that slides with the lung in the axis of the ultrasound beam and continues to the bottom of the image without fading. • B lines are frequently associated with elevated pulmonary capillary wedge pressure and/or reduced LV ejection fraction.
Color Doppler aliasing	PISA	Cardiac flow orifice	• By lowering the Nyquist limit and/or shifting the baseline in the direction of flow, one amplifies the size of the flow convergence at a regurgitant or stenotic orifice, allowing stroke volume calculations to quantify flow with PISA calculation. It intentionally induces color Doppler aliasing for better definition of the PISA shell. • The PISA method is most commonly used for MR quantification but can be used for any flow through an orifice (such as mitral stenosis, ASD, VSD, etc.).
Color Doppler side lobe	Color splay	Mitral valve	• Generated by strong reflectors in the mitral region such as mitral calcifications or prosthetic material. • Since the transducer sweeps the imaging window in a radial direction, the artifact is generated in an arc-like shape at both sides of a strong reflector. • It may be an indirect sign of the presence of clinically significant MR in patients with challenging valve lesions or suboptimal image quality.
3D echocardiography	3D stitching	Any multibeat 3D image	• The image looks divided between subvolumes. • Stitching artifact can be used as a tool for determining the exact anatomic orientation of cardiac structures or detecting pathology such as mitral valve proleptic segment.
Prosthetic valve click	Spectral Doppler click	Mechanical prostheses	• The absence of these prominent clicks suggests possible prostheses malfunction and warrants further investigation.
Tiger stripes	Spectral Doppler artifact	Oscillating structure	• It can be helpful diagnostically to look for the oscillating structure within the Doppler beam path that generates this artifact.

ASD, Atrial septal defect; *VSD*, ventricular septal defect.

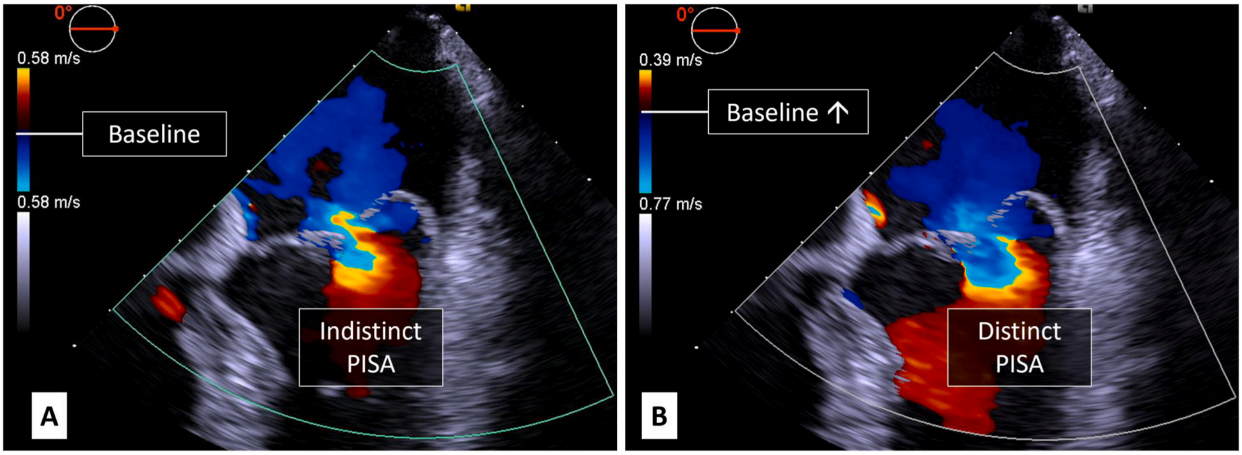

Figure 44 Color Doppler aliasing for the PISA method. Two-dimensional TEE midesophageal view, color Doppler evaluation of mitral regurgitant jet, demonstrates the beneficial use of color Doppler aliasing to measure the PISA radius. Note that by shifting the color baseline, one converts an indistinct **(A)** to a distinct **(B)** PISA shell.

CONFLICTS OF INTEREST

K.B. is on the CCI Board of Advisors Eric Paredes Save a Life Foundation–Sonographer for Youth Heart Screenings and a Consultant for Caption Health Clinical Specialist for Lantheus Medical Imaging. B.C. is an American College of Cardiology Credentialing and Member Services Committee Member. F.F. has received speaker fees from Philips. A.K. is the Vice-Chair, Joint Review Committee on Education in Cardiovascular Technology, EPIC Cardiology steering committee member, and Duke Civility Champion, Duke "Stepping in 4 Respect" leader. S.W. is on the Lantheus Medical Imaging speakers bureau and is a clinical specialist on the Bristol Myers Squibb speakers bureau. The remaining authors have nothing to disclose.

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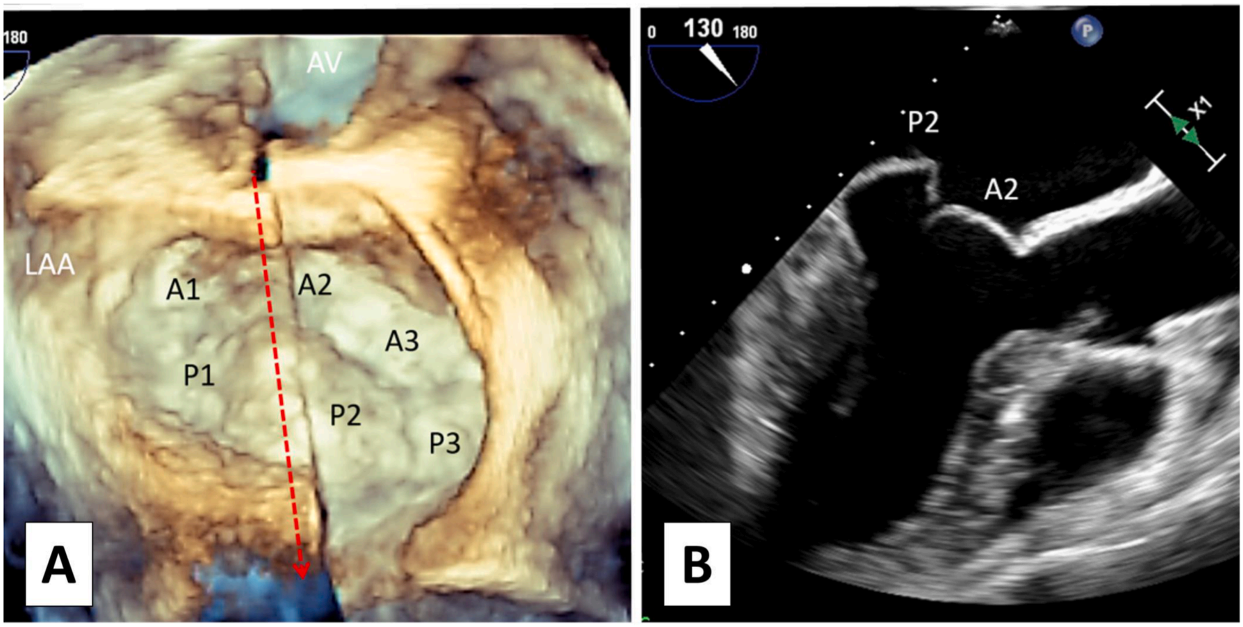

Figure 45 Three-dimensional stitching artifacts as a navigation tool. **(A)** A single frame from a two-beat 3D TEE zoom image of a mitral valve with prolapse of the P2 scallop of the posterior mitral valve leaflet with a stitching artifact *(red dotted arrow)* across the A2/P2 coaptation line. **(B)** The exact corresponding cut on 2D TEE imaging.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.echo.2026.01.007.

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